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Advanced and natural interaction system for motion-impaired users

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HACEN CONSTAR:

Que la memoria titulada *Advanced and natural interaction system for motion- impaired users* ha sido realizada por Cristina Suemay Manresa Yee bajo nuestra dirección en el Departamento de Matemáticas e Informática de la Universitat de les Illes Balears y constituye la tesis para optar al Grado de Doctor en Informática.

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Abstract

Human-computer interaction (HCI) is an important area that searches for better and more comfortable systems to promote communication between humans and machines. Due to the development of new technologies, the cost decrease of technological devices, the increase of processing speed and other factors, we can achieve new systems which provide new channels of communication between persons and computers. Visual information is very important in human-human interaction, therefore, vision-based interfaces can offer a more natural and appealing way of communication. Moreover, it can help in the e-accessibility component of the e-inclusion.

When developing an input device to communicate users with computers, we have to ask ourselves: “What is a good product design: a great technological and innovative product or a useful and usable product for the intended audience?” The answer is to develop a usable system. We have to take into account that the end-user must consider the use of this device effective, efficient and satisfactory, if not he will abandon it.

The research’s main contribution is SINA, a hands-free interface based on computer vision techniques for motion impaired users. This interface does not require the user to use his upper body limbs as other input devices demand, therefore users with motion difficulties can take advantage of this kind of system when standard devices are not suitable for them. Furthermore, while most assistive devices are invasive and some of them very expensive, this interface uses only a standard webcam and free software, consequently it is non-invasive and low cost. Yet, VBI face difficulties due to user differences, lighting conditions or cluttered backgrounds.

In order to develop the system we propose a new mixture of computer vision techniques some of wich have been improved to increase the stability and robustness of the system in order to carry out a satisfactory interaction between the user and the computer.

Besides the technical aspect, user's satisfaction when using an interface is a critical issue. The approach that we have adopted is to integrate usability evaluation at relevant points of the software development. We will present the development process which follows a prototyping system with multiple evaluations with end-users. These evaluations involve users' observation and objective tests. We show how their feedback has helped to improve greatly the quality of the developed software and we want to contribute with a possible framework to follow when implementing vision-based interfaces.

Key words: Human-computer interaction; Vision-based interfaces; Usability; Accesibility.

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Chapter 1

Introduction

Leonardo Da Vinci combined art and science and aesthetics and engineering, that kind of unity is needed once again.
Ben Shneiderman.

1.1 Motivation - The Domain of Interest

Working with new technologies is possible, once access to the input device is solved. Computer and network technologies can help to support and assist in educational, employment and leisure purposes, but achieving these aims requires the possibility of communicating the user with the computer, that is, the computer must be accessible. The design of input and output devices created to allow interaction between humans and computers has to be as universal as possible, where universal means useful and usable for many people. Users presenting limited physical capabilities find difficulties in the access to the computer. The traditional input devices, the keyboard and mouse, may not be the best input devices for all users due to their capabilities, for example, difficulties in using these devices can arise from tremors in hands, motion limitation in hands or arms or stiff finger configuration. Therefore, alternative systems have been developed such as voice recognition systems, computer vision systems, mouth sticks or switches. These devices have limitations and consequently, every user should search for the most functional device for their use.

Computer vision interfaces can provide an easier and friendlier interaction with computers to disabled people as they can be non-invasive, marker-free and they offer a more “natural” communication, that is, the computer is able to exploit humans’ perceptive abilities and use the information for human-computer interaction.

This dissertation will focus on the development and evaluation of an interface based in computer vision using only a webcam, therefore achieving a low cost system. This computer vision system is a pointing device which includes all the mouse’s functionalities: pointing and event execution. The system’s evolution has been very dependent on the contributions of the end-users and their feedback has helped to enhance and modify the system in terms of usability and making the system really useful for them and people with similar profiles.

1.2 Aims of the research

This research has a number of complementary aims, enumerated below:

1. Analysis of the needs and requirements of disabled users that can not efficiently use the traditional input devices to interact with a computer: before developing an input system for disabled people it is necessary to study and analyze systems which they are currently using, their advantages and disadvantages, the needs and the problems the users encounter.

2. Development of the system using a prototyping system: it is very important for a good product design that the user participates in the overall development cycle of the product: no one can substitute the real users. When designing a product we must take into consideration that usability means focusing on the users. We have to know them, observe them, talk to them and interview them, visit them in their working environment, know the tasks they carry out and compile as much information as we can in order to design and develop a usable product.

3. Development of a hands-free interface using computer vision techniques: we have used a new mix of computer vision techniques in order to achieve an interface for people with disabilities which can control their head. In our system, we had to solve issues such as user detection, features extraction, features tracking and translating the information on the image to the system.

4. Usability evaluation: an International standard, ISO 9241-11 on the Ergonomic requirements for office work with visual display terminals, provides guidance on usability and defines it as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". In order to know how usable the interface actually is and how the users feel while operating with it, once the system is steady, we have to carry out:

   - Satisfaction questionnaires to the users.
   - Formal testing to measure different parameters to study the usability, for example throughput, efficiency, subjective information of the user or rate of errors. This will give us a measurement for effectiveness, efficiency and satisfaction.
   - Comparisons with similar and alternative systems.

1.3 Research Methodology

The research methodology in this thesis will be a combination of experimentation, literature analysis and technical development of software. It would have not been possible to achieve a usable input device and to make the best design and development decisions with the lack of any of these three methods. This work is composed of two parts:

1. **Development of a vision-based interface**: we need a computer vision base in order to achieve a vision-based interface (VBI) for users with motor disabilities. When a body part is used to move the cursor in a VBI context,

three processes have to be carried out successfully: the correct detection of the body part, its accurate tracking and finally the translation of the tracking data into a cursor's position. Different techniques and methods can be used in order to achieve the best results in each of the process steps. It is important to review the existing literature to learn about computer vision techniques and to have a base for designing and developing new algorithms. Besides, a great number of alternate pointing devices also exist, therefore it is necessary to study the current situation and estimate the advantages and disadvantages of each of the existing access devices. Finally, all this information will help us design and implement the new system.

2. **Evaluation of the vision-based interface**: a usability evaluation of the designed and developed interface has to be done. Experimentation is the best accepted method in human factors research. We have to focus our system to the real end-users. We need to involve the users in the overall process of the system's design. Literature review is necessary to study different usability testing techniques: how to plan and prepare our usability tests and finally conduct and use the results of the tests to our advantage. We have used a prototyping methodology and cerebral palsy end-users and non-disabled users have participated in the entire process offering their valuable feedback in order to improve the system.

1.4 Thesis outline

The remainder of this document is organized as follows. Chapter 2 covers the human-computer interaction related to motor disabled people, a list of assistive devices that motion impaired users can use to communicate themselves with the computer and an overview of how usability can be evaluated when talking about pointing devices. In Chapter 3, we investigate vision-based interfaces as an example of input device, we review the literature of similar existing interfaces and we describe our hands-free system and the development process we followed. We list the improvements done to the design and the development of the inteface using the users' feedback. Our experience evaluating the hands-free interface with cerebral palsy users and with non-disabled users is detailed in Chapter 4. Finally, the last chapter summarizes our work, provides an outlook to its potentials and implications and concludes this dissertation.

Chapter 2

Human-Computer Interaction, Input Devices and Motor Disabilities

Accessibility is right - not privilege.
W. Loughborough.

Working with new technologies is possible, once the access to the input device is solved. Users with no motor limitation can use standard access devices such as the mouse and the keyboard to communicate with the computer. How can users with motor impairment interact with the computer? Initially, assistive technologies for disabled users were designed with the idea to use the already existing resources in our society, that is, objects and tools that were designed for users with no impairments. Consequently designers had not thought about the difficulties that their creations led to users with disabilities. Therefore we have to stress the importance of designing services and products which are adapted to the population diversity without distinction in their physical, cognitive or social conditions, that is, we have to carry out Universal Design or Design for All. Its focus is not specifically on people with disabilities, but all people, taking into account that everybody has a disability. Factors such as aging or using glasses could be considered a disability. This new approach constituted a new resolution defined in the Spanish Law 51/2003 [12] of equal opportunities, no discrimination and universal accessibility for disabled persons. In its Chapter I, Art. 1 this concept is defined as "the activity which conceives from the beginning, whenever it is possible, environments, processes, properties, products, services, objects, instruments, devices or tools, in a way which can be used by all persons to the greatest extent possible".

Although Universal Design should be the aim to achieve, there are objects in our society that some population sectors cannot use. To compensate part of this fact, assistive technologies were created. These technologies are those objects which are focused on the individual, things that compensate or help a function in case of disability. "Assistive technology is any item, piece of equipment, or system, whether acquired commercially, modified, or customized, that is commonly used to increase, maintain, or improve functional capabilities of individuals with disabilities" [92].

2.1 Introduction

Information and Communication Technologies (ICT) are present in many of our daily activities. Even if information systems are regularly used in education, work, leisure or domestic purposes by the majority of modern societies' citizens, still some sectors such as disabled people or elderly people are at a disadvantage. This phenomenon is called the digital divide, that is, the gap between people with effective access to the information and communication technologies and those without. In recent years, many research activities have focused on designs that aim to produce universally accessible systems that can be used by everyone, regardless of their physical or cognitive skills [77]. Users have different capabilities and abilities, and therefore interfaces should adjust to these differences so that users can use them and perform correctly. No one should find a barrier in the use of something just because of his or her personal differences [4].

Nowadays, great efforts are being carried out in our society to offer accessibility to the new technologies to disabled persons. The idea is to create a society where all their citizens have equal chances and opportunities, and therefore avoiding the digital divide. In Granollers et al [40], accessibility is said to represent:

- A social benefit: accessibility to new technologies can offer people with disabilities more independency.
- A benefit for all: not only users with disabilities benefit from the accessibility. Other sectors also can take advantage of the adaptations. People with temporary disabilities, for example, from an accident or illness can also use the accessibility options that the applications offer. Moreover, when planning a system to answer accessibility needs, it usually improves the usability and everyone can benefit from this fact.
- A technological benefit: accessible design helps the use of new technologies and therefore a division of market's sectors. For example, visual impaired users can work with a standard keyboard or with a special keyboard with big keys or letters. Or instead of using the most common web browsers, other applications can provide better performance with other browsers.
- Economic benefit: accessibility offers the possibility to use new technologies to a big group of people, and if companies are prepared (for example with accessible web pages) they can acquire new customers.

Besides all the benefits that accessibility offers to our society it is also an aspect regulated by law and ethical codes and norms. Some of the norms and laws in Spain are [114]:

1. The Europe's Information Society of the European Commission promote the "eAccessibility" in projects such as i2010 (the Information Space innovation & investment in R&D Inclusion [49]). Their aim is to ensure access to the ICTs to people with disabilities and elderly people on an equal basis as others. This includes removing the barriers encountered when trying to access and use ICT products, services and applications.

2. Info XXI Action Plan: it is an Action Plan approved by the Spanish Council of Ministers in 2001 that aims at providing a detailed roadmap for the implementation of the 'Info XXI' action plan initiative that complies with the commitments of the e-Europe initiative.

3. The Asociación Española de Normalización y Certificación (AENOR) defined the norm UNE 139801:2003 "Aplicaciones informáticas para personas con discapacidad. Requisitos de accesibilidad al ordenador. Hardware [1]" and UNE 139802:2003, "Aplicaciones informáticas para personas con discapacidad. Requisitos de accesibilidad al ordenador. Software [2]" which are based in two older norms that appeared in 1998: UNE 139801:1998 EX for hardware and UNE 139802:1998 EX for software. The norms list requirements that affect issues such as keyboard and screen properties, sounds and multimedia, documentation and so on.

4. Law 56/2007 of December 28 [11], "Measures to Promote the Information Society", that replaces the Law 34/2002 of July 11, "Services of the information society and the electronic commerce" (LSSICE in Spanish).

5. Law 51/2003 of December 2, "Equal opportunities, non discrimination and universal accessibility for people with disabilities". In this law, there is a resolution where the basic conditions for accessibility are established , non discrimination to the access and use of the technologies, products and services related with the Information Society and means for social communication.

6. The Madrid Declaration: the European Congress on Disability adopted the Madrid Declaration, "Non-discrimination plus Positive Action results in Social Inclusion", in 2002 which promotes a new model for achieving the complete social inclusion and integration of everyone.

[1] Computer applications for people with disabilities. Accessibility requirements to the computer. Hardware

[2] Computer applications for people with disabilities. Accessibility requirements to the computer. Software

As seen, accessibility is an essential issue, therefore it is important the research and development of devices that allow access to computers and will help in e-Inclusion and e-Accessibility issues of people with disabilities. In this dissertation we want to contribute to the accessibility of motion impaired users.

Different diseases and injuries may cause a person not to be able to have a total control of their physical motor capabilities causing them to have restricted motion, poor body coordination, reduced strength, spasms or tremors. Sears et al. [99] remarks four categories of physical impairments (PI):

- Structural deviations: cases where there is a significant deviation or loss, partial or total, of a body part, for example a missing finger or a body part that diverts the norm in either position or dimension.

- Mobility (of bone and joint) functions: this issue addresses the user's ability to move a joint or bone.

- Muscle power functions: this issue addresses the user's capability to generate force by contracting a muscle or muscle group. It can regard the partial or total loss of muscle power. Conditions such as muscle tone or endurance can also be taken into account, but for HCI purposes it is not so critical.

- Motor functions: this issue focuses on the user's ability to control voluntary and involuntary movements. An example of a voluntary movement is the difficulty controlling a movement that involves a fast change of direction and an involuntary movement could be tremors or unsteady hands.

Main motor disabilities are due to traumatic injuries, diseases such as, spinal cord injury [3], cerebral palsy[4], loss or damage of limbs and congenital conditions such as

[3]It is damage to the spinal cord that causes loss of sensation and motor control, normally caused by accidents, tumours etc. Paralysis of the legs is called paraplegia. Paralysis of the legs and arms is called quadriplegia.

[4]It is a brain injury that typically occurs before, during or shortly after birth and permanently affects body movement and muscle coordination.

muscular dystrophy[5], multiple sclerosis[6], spine bifida[7], amyotrophic lateral sclerosi[8], arthritis or Parkinson's disease[9] [48].

Users with any of these conditions may not be capable of effectively using the traditional computer input devices, but nowadays many different human-computer interfaces are available and they take the requirements of people with different capacities into account. In following sections, we will list different computer input devices used by people with motor impairment disabilities.

In Spain, according to the provisional data of the "Encuesta de Discapacidad, Autonomía Personal y situaciones de Dependencia"(EDAD) [10] carried out 2008 (the last one was from 1999) by the Instituto Nacional de Estadística (INE) [11], the number of persons with disability reached 3.8 millions, that is, 8.5% of the population. There are 1.39 millions that cannot carry out basic activities without help. Four of every ten persons older than six years with disability have deficiencies in bones and joints.

The main groups of disabilities in people older than six years living at home are: mobility (6% of the population), domestic life (4.9%) and self-care (4.3%), see Table 2.1. So it is a fact that we live in a society with a diverse population and therefore, the analysis, design, development and evaluation of new access devices is a key issue to allow different users to access new technologies.

[5]It is a genetic disorder in which the genes for muscle proteins are damaged. It is characterized by the progressive degeneration of the muscles.

[6]The myelin erodes, rendering the nerve fibres incapable of sending signals from the central nervous system to the muscles of the body.

[7]It is a congenital condition in which the spine fails to close properly during the first month of pregnancy. This causes the membrane around the spinal column to protrude through the back.

[8]It is a degenerative disease that prevents neurons from sending impulses to the muscles. The muscles weaken over time

[9]It is a disorder of the central nervous system that causes uncontrollable tremors and/or rigidity in the muscles.

[10]Survey on Disability, personal Autonomy and Dependence situations

[11]Spanish National Statistics Institute

Number of persons in thousands and rates per 1.000 inhabitants						
	Both gender		Male		Female	
	Nº of persons	Rate per 1000	Nº of persons	Rate per 1000	Nº of persons	Rate per 1000
TOTAL	3787.4	89.70	1510.9	72.58	2276.5	106.35
Vision	979.0	23.19	371.3	17.84	607.7	28.39
Hearing	1064.1	25.20	455.7	21.88	608.5	28.43
Communication	734.2	17.39	336.6	16.17	397.5	18.57
Learning tasks to carry out	630.0	14.92	264.5	12.70	365.5	17.07
Mobility	2535.4	60.05	881.5	42.34	1653.9	77.27
Self-care	1824.5	43.21	645.0	30.98	1179.5	55.10
Domestic life	2079.2	49.24	605.8	29.10	1473.4	68.83
Personal relationships	621.2	14.71	291.7	14.01	329.5	15.39

Table 2.1: People older than six years with disability depending on their disability group.

2.2 Human-computer interaction

The term human-computer interaction (HCI) refers to the way a human and a computer communicate using a common set of physical or logical rules. It refers to the way a person experiences the computer, its application programmes, hardware components, or with the input and output devices. It includes all aspects of the human's experience from the obvious ones of screen layout and selection options as well as the accessibility of the input and output devices [102], see Fig. 2.1. In human-computer interaction, Dix et al [22] define:

- The user as an individual person, users working in a group or a sequence of users in an organization, each dealing with some part of the task or process.
- The computer is any technology used, for example a desktop computer or a large-scale computer system.
- Interaction is the direct or indirect communication between the user and the computer. An example of direct communication would be a dialog with feed-

back and control during the performance of the task whereas indirect would be a batch processing or intelligent sensors controlling the environment.

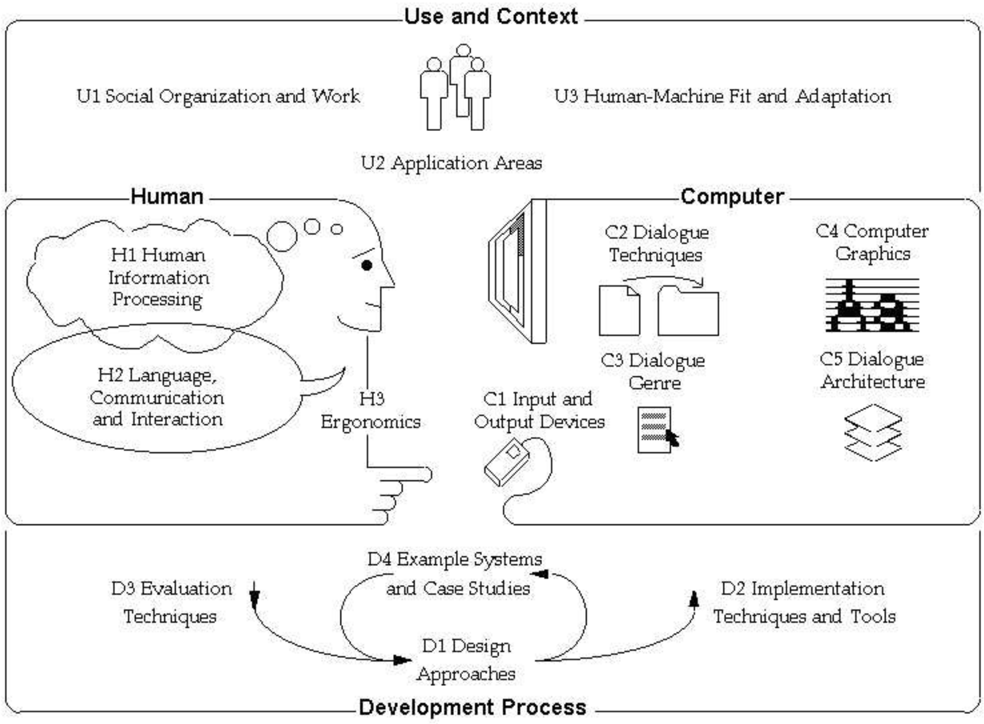


Figure 2.1: Human-Computer Interaction [44].

Since computers appeared, researchers have been conceiving forms of interaction between persons and machines. Therefore, the term and the field of human-computer interaction was born as a discipline concerned with "the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" [44]. The HCI arises as a multidisciplinary field especially concerned within several disciplines: computer science (application design and engineering of human interfaces), psychology (the application of theories of cognitive processes and the empirical analysis of user behaviour), sociology and anthropology (interactions between technology, work, and organization) and industrial design (interactive products). Because human-computer interaction studies a human and a machine in communication, it draws from supporting knowledge on both the machine and the human side. On the machine side, techniques in computer graphics, operating systems, programming languages, and development environments are relevant. On the human side, communication theory, graphic and industrial design disciplines, linguistics, social sciences, cognitive psychology, and human performance are also important. And, of course, engineering and design methods are significant [44]. In Fig. 2.2 we can see the main fields of the HCI.

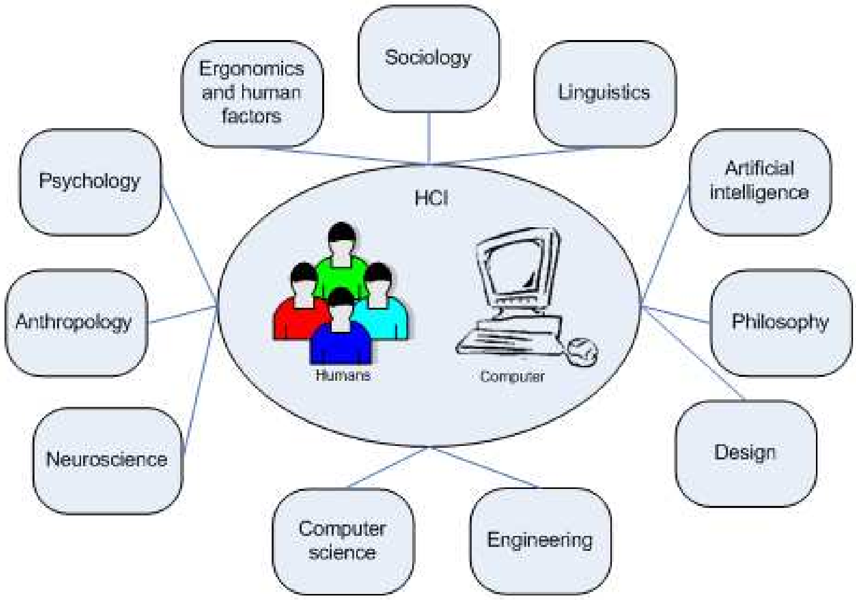


Figure 2.2: HCI fields.

The goals to be achieved in good human computer interaction are error diminishment, user's satisfaction increase and better performance of the tasks involving human and computers. In order to achieve this communication, an interface is needed. An interface is a group of devices, logical and physical, that allows a particular and accurate way of interacting with a computer [60]. An interface is a contact surface between two entities [57]. In human-computer interaction these entities are the human and the computer. The user interface is the main contact point between the user and the computer; it is the system's part that the user sees, hears, touches and through which the user communicates.

To attain a high quality human-computer interaction, user interfaces paradigms have suffered a great evolution and have adapted themselves to the technological advances at every stage. Since the birth of computers, many endeavours to enhance their performance have been carried out and different interacting systems have been used, ranging from punch cards to virtual reality systems, see Fig. 2.3.

Figure 2.3: Examples of interfaces used for interacting with the computer: (a) punch card, (b) first mouse, (c) Microsoft keyboard, (d) Nintendo Wii remote.

In the early stages of computer science, interaction was achieved through punched cards or switches. It was a very unfriendly and complex way. Then command-line interfaces appeared in the 70's, first using teletype terminals and later electronic keyboards and text-based monitor. It was a first approach to an easier and friendlier way of interaction. It was called the typewriter paradigm and the communication with the machine was only through text and had to comply with rigid protocols. In the 80's, Graphical User Interfaces (GUIs) together with WIMP (Windows, Icons, Menus and a Pointing device) were born in Xerox PARC. It was a revolutionary interaction paradigm, the desktop paradigm, which greatly increased the intuitiveness of the users. Together with the WIMP-based GUIs, pointing devices were born to interact with them. Nowadays, the desktop paradigm is universally used in most operating systems, although research is looking for new kinds of interaction that will work with one or several different information sources such as sound, tactile or visual data. Moreover, the research of new human-computer interfaces has also become a growing field in computer science, which aims to attain the development of more natural, intuitive, efficient and satisfactory interfaces. In addition, devices different to computers such as hand phones, PDAs, intelligent electrical appliances or others, are invading our society and while they too are in need of an interface, they can also benefit from the research done on computers, by applying an adaptation to their characteristics.

Turk and Robertson [110] discuss that user interfaces can be classified into three possible categories although sometimes they become overlapping categories according to the kind of input and output they accept or provide:

- Perceptive user interfaces: they provide the computer with human-like perceptual capabilities, so that implicit and explicit information about the user and their environment can be conveniently acquired. The machine is able to see, hear or sense.

- Multimodal user interfaces: they exploit multiple forms of input and/or output. In multimodal UI, various modalities can be used independently or simultaneously.

- Multimedia user interfaces: they are focused on the media, such as text, graphics or sound. Multimedia research is a subset of multimodal output research. To be more precise, multimedia normally focuses on the media used, and multimodality concentrates on the human perceptual channels such as sight or hearing .

The fusion of all these interfaces has led to the concept of Perceptual User Interfaces (PUIs) that are turning out to be very popular as they seek to make the user interface more natural and compelling by taking advantage of the ways in which people naturally interact with each other and with the world. PUIs can use speech and sound recognition (ASR) and generation (TTS), computer vision, graphical animation and visualization, language understanding, touch-based sensing and feedback (haptics), learning, user modelling and dialog management.

In Shneiderman [102] it is commented that any system whose use is intended for human-computer interaction has to decide what is acceptable for the next requirements:

- Time to learn: it is the length of time that takes to learn how to use the interface. With complicated interfaces, learning happens in "plateaus", see Fig. 2.4).

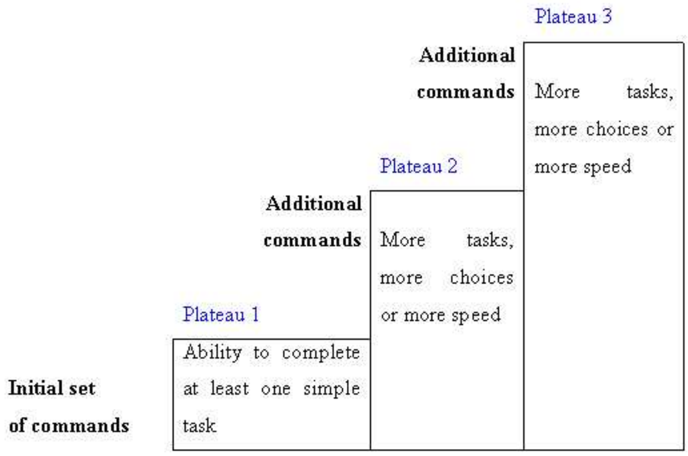


Figure 2.4: 'Plateaus' of time to learn.

- Speed of performance: it is the speed of the user interface, not the speed of the software. It is the number of characters to type, buttons to press, mouse-clicks or mouse movements to execute to carry out an operation. This issue normally conflicts with the time to learn requirement, because normally the faster systems are the harder ones to learn.

- Rate of errors by users: the rate of errors produced by a user can be due to a bad structure of the user interface. It is affected by factors such as consistency or arrangement of screens in GUIs.

- Retention over time: the closer the syntax of the operations match the user's understanding the easier it will be to remember how to operate the interface. If the time to learn is fast, then the retention will be less important.

- Subjective satisfaction: it refers to how comfortable the user feels with the software. This is a difficult criterion to measure, and it depends on the user's individual preference and background.

- Real-time response from the computer for feedback purposes: in the case of human-computer interfaces, a system operates in real-time if the user does not perceive a delay between his action and the system's response.

2.3 Hardware and Software Input Devices for Disabled people

Persons with disabilities are frequently unable to use a computer, because they cannot find proper devices or interfaces for their interaction or they cannot afford commercial solutions. Problems or obstacles that users with disabilities face, differ depending on their limitations and disabilities. Three phases can be critical in the interaction with a computer for a disabled user: the input, the processing and the output of information, see Fig. 2.5. On the one hand, if we take into consideration motor difficulties, the main problem in the communication is the input of data into the system. For example, the use of a mouse or a keyboard demands accuracy and motor coordination. On the other hand if we consider sensorial restrictions such as users with hearing problems or short-sighted, the main inconvenience encountered in the communication is the output from the computer. Finally, the main obstacle for users with cognitive barriers is to understand the information, the processing. Moreover, they can also have difficulties with the input and output although this is due to their comprehension. The interaction with the computer or an application requires the user to understand the procedures needed to carry out the tasks. In this dissertation, we will focus on input devices, the principal critical phase for motion impaired users.

A few important properties characterize most input devices, and therefore different classifications of input devices exist. Hinckley [45] states that following aspects can be taken into account when classifying the input devices:

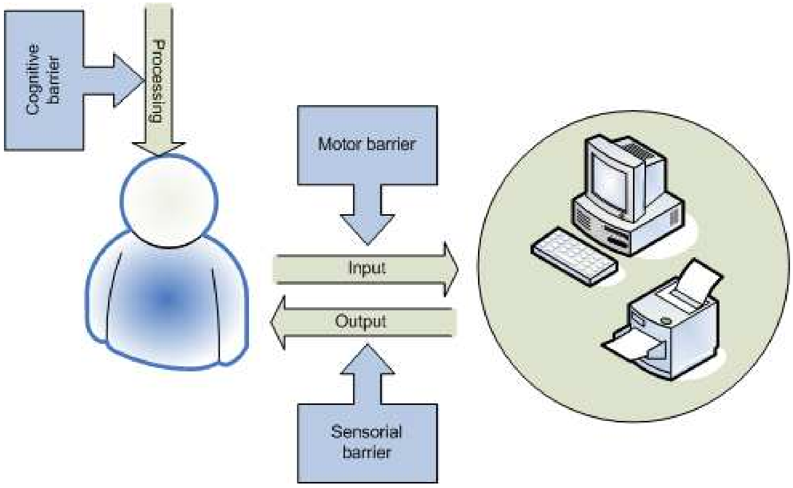


Figure 2.5: Difficulties found in HCI.

- Property sensed: most of the input devices sense linear position, motion (e.g. mouse) or force (e.g isometric joystick). If we are treating with rotatory devices, then angles, change in angles or torque is also considered (e.g. trackball).

- Number of degrees of freedom involved: devices sense one or more dimensions. For example a mouse senses two linear dimensions of motion, 3D input devices sense three or more simultaneous dimensions of spatial position or orientation.

- Indirect versus direct input device: a mouse is considered an indirect input device because the user moves the mouse to indicate a position in the screen, whereas in a direct input device the input and the display surface is unified, like for example in a touch screen.

- Device acquisition time: is the average time needed for the user to be able to use the device. For example, with a mouse, the acquisition time is the average time it takes to move a hand towards the device.

- Other metrics: system designers should take into account other performance metrics, including pointing speed and accuracy, error rates or learning time.

To classify input devices for motor disabled users, besides all the technical characteristics of the device, one important issue is the standardization, that is, the normalization. Normalization means to allow persons with some kind of disability lead a life as similar as the collectives considered as “normal” [7].

Following this normalization criterion, we can classify the access devices:

- Standard devices: devices that are used in a generalized way.
- Assistive devices: when the standard device is not effective enough to allow a good human-computer interaction, there are devices that emulate the keyboard or the mouse.

Together with the assistive devices or directly over the standard input devices it can also be used:

- Adaptations: resources that facilitate the access and use of a standard device or an assistive device like for example a head wand or a switch.
- Personalization of the assistive devices: personal strategy of the user to use an adaptation or a device in the most effective manner. For example, positioning a device at a particular height or using different systems to hold or adjust an adaptation, see Fig. 2.6 .

Figure 2.6: Height adjustment to use a trackball with the chin and an extensible arm to use a switch with the chin or the head.

2.3.1 Standard devices

Keyboard

A keyboard is a device modelled after the typewriter which uses an arrangement of buttons (keys) which act as electronic switches. Cooper [17] presents an exhaustive history of the development of the computer keyboard. Different design features, including key size and shape, keyboard height, size and slope, and the force required to activate keys classify the standard keyboards in answer to issues such as ergonomics or potential users. An important keyboard's property is the layout. There are a number of different arrangements of alphabetic, numeric, and punctuation symbols on keys. QWERTY layout is the most common one, but not the most suitable for ergonomics or for speed. This layout was born due to the mechanical limitations of the typewriter, because users that wrote fast used to jam the levers. DVORAK keyboard layouts reduce the amount of motion required to type common English text, see Fig. 2.7; therefore it is supposed to maximize typing efficiency [26]. There are other layouts like ABC, Opti or QWERTZ and many research works and evaluations trying to proof which one is better, but results have shown varied, sometimes opposite results depending on which work is read [76, 58]. This property is specially interesting for users with one functional hand alone, as different layouts are prepared for working with only one hand.

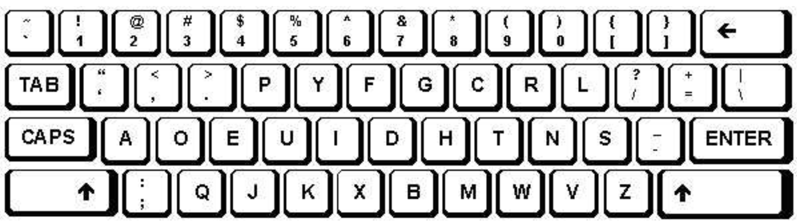


Figure 2.7: DVORAK layout.

Ergonomics keyboards are available too nowadays. They normally have a convex, tilted and rotated surface and the keys are splited into two sections helping a more natural wrist and arm alignment and avoiding Repetitive Strain Injury (RSI). Examples of this kind of keyboards are the Microsoft Natural Keyboard, Goldtouch Adjustable Ergonomic Keyboard or Kinesis Ergonomic Keyboard. Others like Safetype Keyboard Works change our view of the keyboard, developing a vertical ergonomic keyboard. Moreover, for disabled users we can also find keyboards with extra big sized keys or with different shapes, see Fig. 2.8.

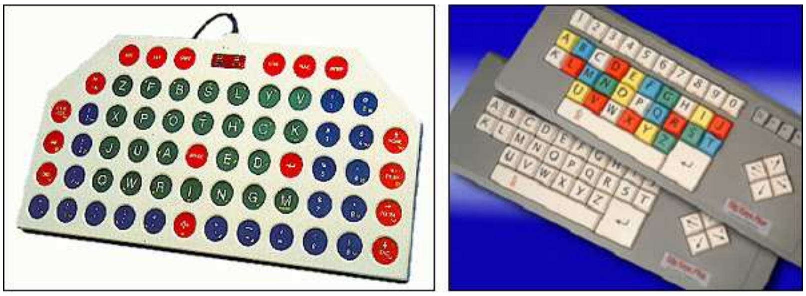


Figure 2.8: Different keyboards.

Mouse

Douglas Engelbart and his colleagues [8] invented the mouse in 1967, and since then it has been one of the most effective input devices working with graphical user interfaces [15, 63]. A mouse is a pointing device that allows the user to navigate within a graphical user interface by detecting the two-dimensional motion relative to its supporting surface and with a wheel and/or with one, two, three or more buttons to execute different events. The speed at which the cursor moves is a function of the speed at which the mouse itself is moved. This relationship is called the mouse gain. Depending on the technology, they can be considered mechanical, optical or optical-mechanical. Mechanical are those where the mouse's speed and distance is determined by a ball moving rollers inside the mouse. Optical mice require a light-emitting diode such as laser or infrared and photodiodes to detect movement relative to the surface. The optical-mechanical mouse consists of a ball which rolls a wheel inside the mouse. This wheel contains a circle of holes which reads the LED through a sensor as it spins around when the mouse is moved. Mice are not too adequate for users that cannot carry out fine hand movements or that present tremors or spasms.

Trackball

A trackball is a ball fitted in a socket that contains sensors to detect the ball's rotation on two axes, see Fig. 2.9. The user rolls the ball with the palm of their hand, with their fingers or only with their thumb, therefore for some users with disabilities is an easier device to access the computer.

Figure 2.9: Trackball.

Joystick

A joystick consists of a stick that pivots on a base and reports its angle or direction to the system, see Fig. 2.10. Motor impaired users can move it with their hands, with their chin, with their tongue or with any other parts of their bodies.

Figure 2.10: Joysticks handled by the hand, the mouth and the chin.

Touchpad

A touchpad is a pointing device consisting of a special surface that can translate the motion and position of a user's fingers to a relative position on the screen, see Fig. 2.11. The operation of the buttons can be done by tapping the surface or by pressing the buttons normally located near the touch surface. Users who can control a finger can use this system as the moving surface is small.

Figure 2.11: Touchpad.

Tablet

Tablets, also known as touch tablets, graphic tablets, or digitizing tablets, sense the absolute position of a pointing device on a flat surface, the tablet. Tablets might be used with the bare finger or a stylus.

Touchscreen

A touchscreen is a display which can detect the presence and location of a touch within the display area normally done by a finger, hand, head wand, mouth stick or other similar device (stylus), see Fig. 2.12.

2.3.2 Assistive devices

Virtual keyboard

A virtual keyboard is a software program, a graphical on-screen keyboard, see Fig. 2.13. This kind of keyboard is ideal for people whose disability prevents him or her from

Figure 2.12: Touchscreen.

typing on a physical keyboard. Normally this kind of system allows the user to configure the size of keys and keyboard, the position of the keypad and the arrangement of the keys. Operating systems usually come with one for accessibility options, and commercial and free ones exist too. The letters are selected using for example a pointing device or a single switch.

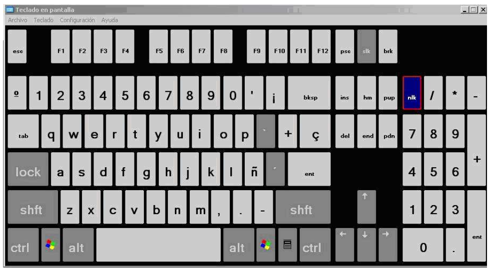


Figure 2.13: Virtual keyboard included in Microsoft Windows.

One-hand keyboard

If a person is only capable of using one hand, right or left, there are one-hand keyboards that will facilitate or that they will be more comfortable to use for typing such as FrogPad, see Fig. 2.14. There are different types, some with many buttons and some with just rows of five buttons (one for each finger), where one key is used for more than a character.

Figure 2.14: Frogpad and Maltron keyboards for one hand.

Virtual mouse

A virtual mouse is a software program, a graphical on-screen mouse, see Fig. 2.15 that includes all the functionalities of a standard mouse and that can be used for example with a switch.

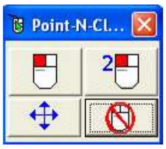


Figure 2.15: Virtual mouse.

Mouse emulators

Mouse emulators are physical devices that replace a standard mouse and all its functions without requiring a hand's accurate control, see Fig. 2.16. The mouse's cursor movement and events are carried out by means of pressing buttons that control each of the possible movements. These buttons can be pressed directly with the hand or by using an adaption: switches, head wands or other device.

Feet Systems

Foot operated input systems can provide effective pointing control [80] if the user has total control of their feet. Systems like NoHandsMouse or FT07-01-02 Footime

Figure 2.16: Mouse emulator Junior and Traton.

Foot Mouse with Programmable Pedal use foot pedals to achieve the mouse's tasks, see Fig. 2.17. These systems are foot operated mouse devices that consist normally in two separate pedals or a scroll and a pedal: one device that operates the pointer, and another one used for button clicking.

Figure 2.17: Feet systems: NoHandsMouse and Footime Foot Mouse.

Vision-based interfaces

Vision-based interfaces use computer vision in order to sense and perceive the user and his actions within an HCI context. They need a device to capture images, a camera, and software to process, analyze and recognize human motion and gestures in real time to use it as an input system in order to interact with the computer. In the following sections, vision-based interfaces will be more detailed.

Voice Recognition Systems

If a user has motion impairment but is able to communicate orally or by producing sounds, there are systems that use voice for human-computer interaction. This kind of software converts sounds, non-verbal vocalization, words and other intonations into cursor movement [64, 65, 18, 70, 104, 43].

Brain Computer Interaction or Electro-encephalogram (EEG), Electro-oculogram (EOG) and Electro-myography (EMG)

Brain Computer Interaction (BCI) is sometimes called a direct neural interface or a brain-machine interface. It is a direct communication pathway between a human brain and an external device. It is a communication system that translates human intentions, reflected by brain signals EEG, into a control signal for an output device such as a computer application, see Fig. 2.18. However, BCI's downside is that they are very sensitive to noise [68].

EMG signals measure muscle response or electrical activity in response to a nerve's stimulation of the muscle. They are much less noise-sensitive than the EEG [30].

Eye-movement tracking can be done by using electro-oculographic signals(EOG) techniques which rely on electrodes mounted on the skin around the eye which measure differences in electric potential in order to detect eye movements and using this information for HCI purposes. Gips and Olivieri [34, 33] developed a system, Eagle Eyes, based on this technology (EOG) to control the mouse and it is nowadays used in schools in the USA, see Fig. 2.18.

A lot of hybrid approaches consolidate different input signals like for example Barreto et al's system [9] that uses EEG and EMG in order to control the cursor's position. One important representative of these mixed systems is Doherty's et al [23] system, the Cyberlink interface, which makes use of EOG, EEG, and EMG input.

Up to now, all these systems are invasive and require users to attach sensors to their body.

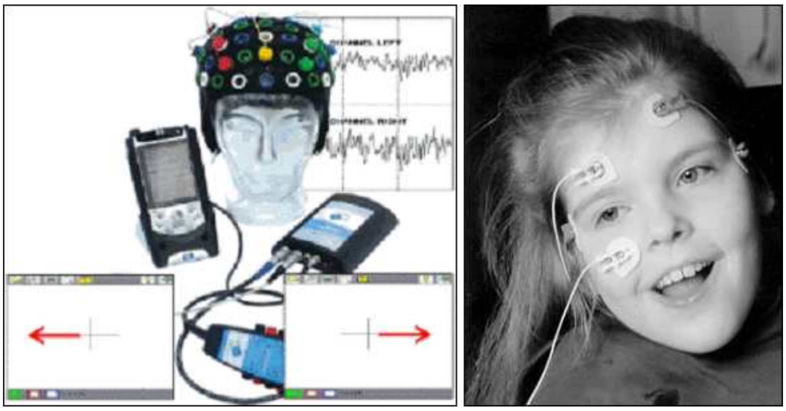


Figure 2.18: G.Tec's BCI and EagleEyes by EagleEyes Project.

2.3.3 Adaptions

Keyguard

People that can use physical keyboards, although with difficulty can put a keyguard, that is, a cover, usually made of plastic or plexiglass, which fits directly over the computer's keyboard. Holes in the cover correspond to each key on the keyboard and guide a finger, head wand, mouth stick or other device to facilitate direct key presses, allowing the user to rest their hand on the surface of the guard to avoid any unintentional movement.

Switch

The switch allows a "switch access", which relies on a single on/off signal to activate events. Switches differ in shape and size depending on the action to carry out. There are many different ways to activate them such as sip-puffing, biting, pushing, pulling or squeezing. A switch can be operated by any body part that is capable of producing a consistent and voluntary movement like thumbs, feet, hand, chin, tongue or any other body part. Usually when operating with the switch by pressing it, it starts to scan through all the menu options, and by pressing it again, it selects the menu option that is currently highlighted. The scanned menu can include letters, numbers or submenus, see Fig. 2.19. More than one switch can be used in order to speed up the tasks to carry out. Although enhancements have been reached to accelerate work with switches such as word prediction or studying the best layouts [3], it is still a very slow input mechanism for text. Moreover, the help of someone is needed to scan positions on the screen.

Figure 2.19: Switches for the hand, chin or foot.

Head wands, mouth, foot or other body part sticks

There are sticks that can be strapped around the head or held in the user's mouth or other controlable user's body parts. By moving the body part, the stick can be used to make physical contact with a keyboard or a trackball to type and navigate, see Fig. 2.20. They are not very expensive and are easy to use, but can be very tiring.

Figure 2.20: Head wand and mouth stick.

2.4 How to choose the best input system

Not all systems are suitable for everyone, therefore the selection of an input system should take into account the user's capabilities and requirements. Users have a set of capabilities (physical, sensorial, ...) to exploit and a set of limitations (physical, cognitive, ...) that hinder their interaction with the computer. The ideal is to find an access system that maximizes the user's capabilities, minimizes the user's limitations and is as normalized as possible. Factors to be considered are:

- Physical capabilities: the access system should not require a great physical effort on the user or movements that he or she is not able to perform easily. The user may have tremors, limited strength or spasms which should be considered. The physical considerations should involve the following issues when trying to identify the most effective access method [100].
  - Controlled voluntary movement: when using any input device, it is important to identify a voluntary and controlled movement that the user can repeat frequently and within a specific time. It is important to discover over which part of their body (hands, feet, head or other) they have major control.
  - Fine motor control: if the user has limited or slow fine motor skills it will be difficult for them to accurately target and activate the input device. Therefore this fact will influence the size, shape and position of the items on a display or the selection set, as well as keyboards, mice, trackballs, and switches.
  - Range of motion: if the user has a limited range of motion, it will be difficult for them to physically reach the target. This will influence the position and choice of input devices.
  - Strength: the user may have little strength or little control of their strength. On the one hand, if the user has limited strength in the part of the body that is going to be used to access the input device it is important to provide an input device that requires little pressure for activating it. On

the other hand, some users may use significant force when operating the device due to poor motor control. Therefore, they need to use robust products firmly mounted in the correct position or with lack of contact.

  – Fatigue: it is important that the access input device is as ergonomic as possible and that it is well positioned to try reducing the user's fatigue.

  – Multiple movements: the normal way to interact with a computer is by using two devices, one for typing and one for navigating trough the graphical interface, a keyboard and a mouse for example. This multiple method access can also be suitable for disabled users, therefore it is difficult to identify the best combination of movements, but if it exists, it will be more effective.

- Cognitive capabilities: the input system should take issues such as the cognitive problems, the attention limitations or memory loss into account, as the parameters of retention over time and the time to learn [102] can be greatly affected.

- Sensorial capabilities: besides the physical limitations presented by motor impaired users, they may experience too sensorial limitations such as short sight or bad hearing that can be important to consider when choosing an input device.

- Personal considerations: the user's preferences are a key requirement in the selection of an input device. If a user has previous knowledge on a system, although it is not the most suitable system for them, it may be difficult to change it. The user's feelings towards being treated differently from others can also be an important obstacle, that is, the user may want to use standard input devices although they require a major effort compared to other systems.

- Environmental conditions: when choosing an input system the environmental conditions wherein it is going to operate should be taken into consideration. For example, a vision-based interface with no special lighting will need a minimum of light for working, or a speech based system will not be able to function adequately in a noisy environment.

- Tasks to carry out: the device selected should allow a complete access to all the applications, but many of the software applications are only suitable for keyboards and mice. Therefore, it is important to study the tasks the user will commonly use and take them into consideration. For example, the use of switches is very limited in order to perform tasks with standard applications.
- Temporal considerations: the input system should be as fast and accurate as possible. For example, using switches can be very slow.
- Financial considerations: the selected input device has to be inside the user's budget, as in the market, input devices can vary from 30ϵ for a trackball to around 8000ϵ for an eye tracker.
- Portability considerations: it is important to plan where the interaction is going to take place: only on one particular computer or it should be able to be portable to any location and computer.
- Normalization criterion: as mentioned before in this dissertation, see Fig. 2.21, the issue of using standard devices can be considered as far as the user feels comfortable.

These considerations often conflict among themselves, and only the end-user is finally the one that actually selects the device. Sherer and Galvin [98] estimated that 1000 assistive technology devices come out each year, but most of them are not tested due to the ignorance of their existence or their costs. If systems do finally reach the user, many are not accepted because of the lack of usefulness to the user: "dissatisfaction typically results in discontinuance of the assistive technology product" [93]. According to Rogers' theory of diffusion [94] there are two types of discontinuance: replacement (change the system for another one) and disenchantment (reject the system due to dissatisfaction). A survey of 227 adults with different disabilities on device selection, acquisition, performance and use showed that 29.3%

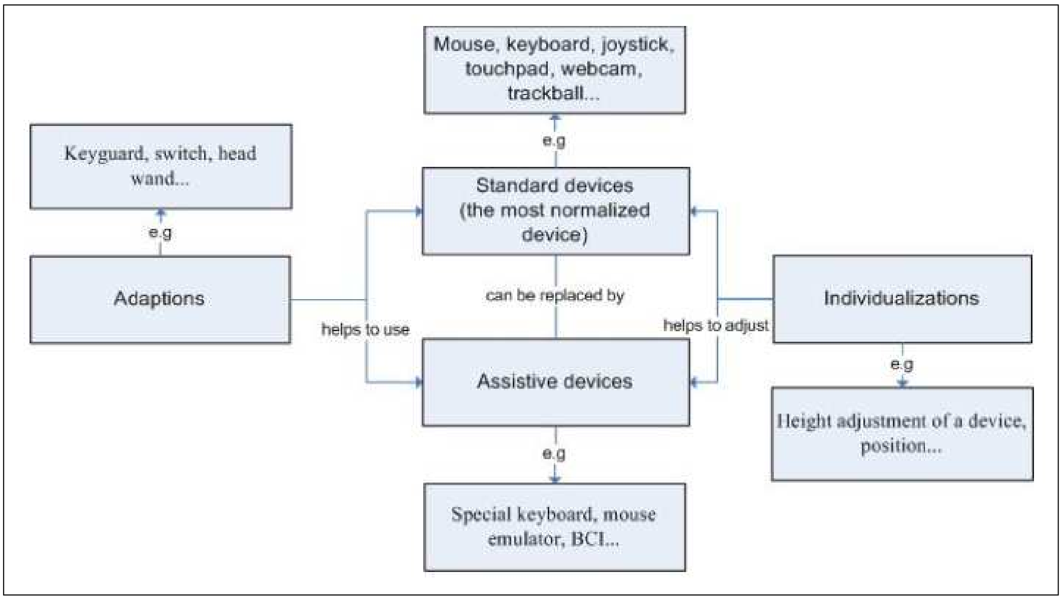


Figure 2.21: Selection of a device taking into account the normalization criterion.

of all devices were completely abandoned due to changes in the individual's needs or priorities, ease of obtaining the device, poor device performance, and whether or not the client's opinion was considered during the selection process. Systems which are difficult to use, waste the user's time, cause frustration and discouragement, and put off further use of the system. Devices more frequently discarded were mobility aids [83]. Other reasons for the abandonment are: unreliable systems, difficulty using devices, environmental barriers, and fear of technology [82, 95].

Knowing this information, it is a fact that real user's opinion must be considered to decrease the discontinuance and to really design useful systems. Therefore it is very important for a good product design that the user participates in the overall development cycle of the product. No one can substitute the real users.

Usable devices may have a great impact in the choice of an input system. To achieve them, usability must be present in the design and development of the product.

2.5 Usability

All HCI interfaces should go through a usability evaluation in order to study how usable the device actually is. When designing a product we must take into consideration that usability means focusing on the users. We have to know them, observe them, talk to them and interview them, visit them in their working environment, know the tasks they carry out and compile as much information as we can in order to design and develop a usable product. Usability is a term that has not been homogeneously defined by standards or researchers but it is a concept that takes multiple factors such as performance, user satisfaction, system's acceptability and ease or learning into consideration. A definition of usability is found in the international standard [12], ISO 9241-11 on the Ergonomic requirements for office work with visual display terminals (VDTs) - Part 11: Guidance on usability, that provides guidance on usability and defines it as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". The three measurements to control according to the ISO 9241-11 are:

- Effectiveness: how good was the task accomplishment, how complete was the aims achievement, how accurately and completely users are able to perform their specified goals.
- Efficiency: the amount of effort that is required to achieve the level of effectiveness in performance of the goals.
- Satisfaction: an answer to the personal expectations of the users, how good do the users feel with their needs fulfillment. A lack of discomfort and a positive attitude towards the system, while performing the goals.

These three parameters are affected by:

[12] Two other Standard definitions for usability are: "The capability of the software product to be understood, learned, used and attractive to the user, when used under specified conditions." [2] "The ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component." [1]

- The users: who is going to be the end-user of the product, are they experienced users or new users, do they have any disability.
- Their goals: what kind of tasks do they want to accomplish when using the product.
- The context of use: where is the product going to be used and under which conditions.

Dumas and Redish [25] define usability as “usability means that the people who use the product can do so quickly and easily to accomplish their own tasks”. And this definition is based on four points:

1. Usability means focusing on users.
2. People use products to be productive.
3. Users are busy people trying to accomplish tasks.
4. Users decide when a product is easy to use.

This definition is similar to the ISO 9241-11 as it considers people, tasks to accomplish, a time reference and product's easiness for the user. Focusing on users means to know who the users are, to understand and work with them. To develope a usable product, we need to consider the real end-users' opinion, the users that are going to work with the product. Talking to people around the end-users can help to make a better requirements' analysis but it is essential to count with the real users' opinion. Designers must be aware that the product has to offer a profit to the user because the product is a tool not a goal: the tasks achievement has to be faster, better, more comfortable or give any other benefits that the user finds in their performance or their personal preferences. Users need the product to be easy to use and to understand.

Moreover, usability is not a one-dimensional property of a user interface as it relates multiple components and Nielsen [72] associates it with five usability attributes (they are very similar to Shneiderman's [102] already commented requirements):

1. Learnability: the easier a system is to learn, the faster the user can bring out a benefit from it, therefore it is desirable for the system or product to be easy to use and understand.

2. Efficiency: the product should be efficient, so once the user knows how to use the system, then he will be able to obtain a high level of productivity.

3. Memorability: it should be easy for the user to remember how to operate with the system.

4. Errors: it is important for the system to have a low rate of errors, an easy recovery from errors if they appear and no catastrophic errors.

5. Satisfaction: it is important for the user to like the system. He or she should be subjectively satisfied by the product.

Utility is another desired factor, Grudin [41] differs between utility and usability where utility is the capability of the product to do what it is needed, the functionality; and usability is how good the users can make use of the product's functionality, for example measuring Nielsen's five attributes. Other factors to accept a system are related to the cost, the reliability or compatibility, see Fig. 2.22.

As seen, there are many possible parameters to control in order to assure the achievement of a usable system. There is no consensus or agreement, although many authors coincide with most of the characteristics to study.

A common issue that all these definitions share, is that users have to be included in the design and development process and we have to control all those factors that may help in producing an efficient, effective and satisfactory product. Gould and Lewis [39], in order to help the inclusion of usability in the overall process, give four principles when developing systems:

1. Focus early and continuously on users.

2. Integrate considerations of all aspects of usability.

3. Test versions with users early and continuously.

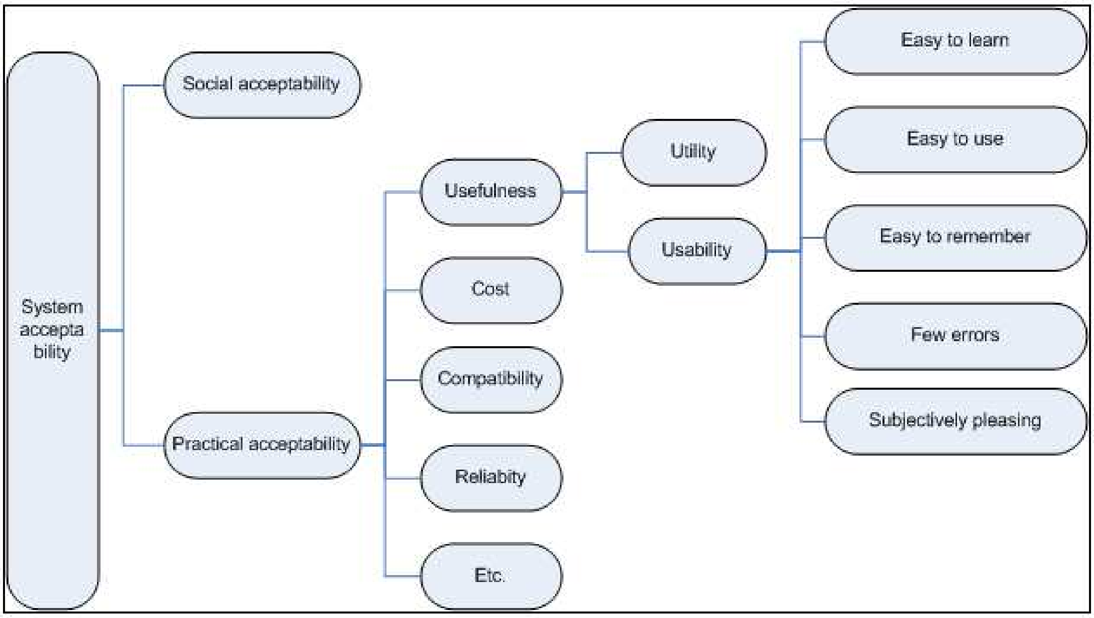


Figure 2.22: Nielsen's model of the attributes of system's acceptability.

4. Iterate the design.

These considerations will help developing functionalities that are really needed and are going to be used. Testing a prototype in early stages will make modifications on the system less costly and the user will participate in the design decisions. Furthermore, costs which appear for maintenance and support tasks also decrease, users need less time to learn the system and the quality of the system increases.

2.5.1 How to evaluate usability

Usually we measure usability in order to better understand the user's needs and requirements and to offer and improve the user's experience. To accept a product as usable, information about the previously mentioned parameters and attributes must be collected. We have to measure them and decide whether the results are considered good enough or not. To obtain this information, end-users have to use the system and perform a set of predefined tasks or in some cases their own tasks. We have to analyze and record all the issues we observe: what is easy or difficult for the users when using the system, how do they use it, how fast do they use it (fast meaning how many buttons, menus do they need to click or windows to go through), how fast do they learn it and all other aspects related with the use of the system.

The ideal is to count with a cross-skill development team expertise in different areas such as computer science, usability or interface design in order to be able to gather all the possible information and apply it in developing the most usable and efficient system or product.

It is important to set quantitative and qualitative goals for the system during the whole process to really evaluate the usability and to help in the design decision process. How to choose those control measurements is a difficult question to answer. Usability cannot be directly measured instead we can find aspects of usability that can be measured. Two types of usability metrics can be collected during a usability test. These metrics are objective and subjective information [25]:

- Performance data: objective data that can be captured during the usability test session and that represents what has actually happened. This information is quantitative, like for example: time to finish a task, time spent recovering from errors, successful task completion rates or error rates.

- Subjective data: subjective data of what the user thought and how he felt while using the application and its interface. Subjective data can be qualitative or quantitative, as for example, if we present a Likert [59] scale [13] and ask the user to rate how easy or difficult a system is to use by using this scale, we will obtain a subjective judgment in a quantitative answer. To measure subjective information we can control ratings of how easy it was to install the product, how easy it was to learn how to use the system, system's preferences or spontaneous comments.

Moreover, Hornbæk [46] identifies in his work those papers that measure usability

[13] A Likert scale is a psychometric scale commonly used in questionnaires, where the respondents specify their level of agreement to a statement.

and how they measure it: he does a review of papers published in core HCI journals or proceedings between 1999 and 2002 where he identifies 180 articles that report the use of measures of usability. Frequently the term usability is defined by those aspects that can be measured and therefore, it is important to select a set of valid measurements of the usability. He classified the measurements in three big groups: effectiveness, efficiency and satisfaction. And then he divided these groups in "subgroups based in part on the usability measures mentioned in prominent text books [72, 22, 102], in a book on behavioral science [69] and in well-known discussions of usability measures [115, 105] and in part on the similarities found in the usability measures used by the studies [he] reviewed". The discussion is to select suitable measures of usability and how to understand the relation between measures. Many discussions have arisen on how to measure the usability and what affects the usability like for example time [21], aesthetics [107, 97], culture [117], feedback, pleasure, graphical display, flow, fun, playfulness and many other issues.

How to measure the effectiveness

Effectiveness has to do with the performance of the tasks, how accurately and completely did the user achieve the goals. In order to measure the accuracy and the completeness it is necessary to indicate a set of operational criterions for considering the achievement of a task. Aspects that can be measured are the number or percentage of task that users successfully complete, the accuracy with which users complete tasks, the error rates, users' accuracy in pointing to or manipulating user interface objects [46].

How to measure the efficiency

Efficiency is the amount of effort that is required to achieve the level of effectiveness in performance of the goals. The efficiency is the relationship between the level of effectiveness and the used resources. It takes into account resources such as time, physical or mental effort or material and economic costs.

How to measure the satisfaction

Frequently satisfaction is measured by means of satisfaction questionnaires. There are different moments where questions can be asked: before carrying out the test, after each task or at the end of the test (set of tasks). Pre-test questionnaire is usually composed to gather information about the user such as background or experience; it will help us to understand and interpret the data obtained and to be able to group users for example by experience. Post-task questionnaires are interesting to get immediate reaction after a particular task to see if the user's perception over time changes among tasks. And finally the post-test questionnaire is done after all the tasks are carried out and therefore, the user has spent time using the system. Usually these questionnaires include general questions that could apply to any product such as "how easy was the system to use?" and there is also a set of specific questions that only apply to the system or product in particular. Moreover, satisfaction is a measurement correlated up to some degree with other usability measures such as effectiveness and efficiency [96, 32]. Some questions in the survey even deal directly with effectiveness and efficiency facts. Hornbæk [46] identified only 12 studies that had used standardized questionnaires or a questionnaire based on previous work such as the Questionnaire for User Interface Satisfaction (QUIS) and components from Davis' [20] questionnaire measures relating to 'technology acceptance' that focuses on 'perceived ease of use' and 'perceived usefulness'.

Concluding this section, we can observe that no agreement on which measurements to use exist. We have to take into account that all the metrics we apply for our evaluation have to be information that can be used to identify effectiveness, efficiency and satisfaction measurements together with other desired usability/acceptability parameters we want to control. Even though we consider other factors, the three measurements included in the ISO 9241-11 should be included in all usability testing as the correlation among these factors is not totally demonstrated [32]. For example, in difficult tasks, efficiency may not be as important as effectiveness and user's satisfaction. Or the satisfaction or preference shown by a user may not coincide with the system which is more efficient for them. Nielsen and Levy [73] analyzed this last correlation between efficiency and preference in 113 cases. Their conclusion is that preference predicts efficiency quite well, but in 25% of the cases it is not correlated. Nevertheless Sauro and Kindlund [96] found correlation among these measurements in their tests (they compute a single, standardized and summated usability metric), but still they agree with Frokjaer et al [32] that it is necessary to measure every factor separately because it adds additional information not contained in the other measures. Moreover, the ISO 9241-11 already advises that it is necessary to measure at least one factor for effectiveness, one for efficiency and one for satisfaction. No general rules exist for choosing and combining these measurements, as they are strongly related to the context applied.

2.5.2 Usability measures for non-keyboard input devices

The European Committee for Standardization has written the standard norm ISO 9241-9, that is, Ergonomic requirements for office work with visual display terminals (DCTs) - part 9: Requirements for non-keyboard input devices, for recommending design requirements for non-keyboard input devices. This norm was stipulated in year 2000 and includes potential methods for testing this kind of systems, but it only includes devices for which there exists sufficient published ergonomic information such as mice, joysticks or trackballs. It does not cover eyetrackers, speech interfaces, head-mounted controllers, datagloves, devices for disabled users, foot-controlled devices or head-based interfaces using computer vision techniques. Besides this fact, there are many design requirements and methods described than can be used to improve and to test our hands free system based on computer vision techniques, as it is a pointing device.

The ISO 9241-9 provides potential methods for testing and evaluating input devices for usability aspects such as efficiency or effectiveness and it also describes comfort-rating scales. The evaluation procedure defines environmental conditions, furniture adjustments, session conditions recommendations, user selection and others.

The ISO 9241-9 document contains two different parts in the evaluation: system factors and human factors. The evaluation of system factors is based on Fitts' law [31] which predicts that the time required to rapidly move to a target area is a function of the distance to and the size of the target, and the evaluation of human factors is a questionnaire that comprises 12 questions about the levels of comfort and effort that are involved in the system's operation. The measure is a 7-point interval Likert scale [59].

There are a set of actions expected from pointing devices where there is no "direct pointing" [14] in order to maximize the control of the interaction with the computer. These actions are [50]:

- Click: event that emulates the depression and release of a button or actuation point on an input device. Working on a operating system, it is interesting to offer all the possibilities that the operating system uses like for example the left button click for selecting, the double left button click for executing or the right button click for bringing out menus.

- Drag: event used to move one or more objects on a display by translating it along a path determined by a pointer.

- Free hand input: the input device controls the movement of the cursor without any constraints following the manual input of the user. For example, using the key arrows for controlling the mouse would not allow the user to move freely.

- Pointing: operation with a graphic user interface in which an input device is used to move a small display image (for example a cursor) to a specific location on the display.

- Selecting: choosing one or more items on a display.

- Tracing: following the outline of an image by moving the cursor or input device over the lines or shape of an image.

[14] "Direct pointing" means to hit the target directly with no help of system feedback, for example selecting directly with a finger an icon in a tablet pc.

- Tracking: moving a pointer of predefined symbol across the surface of a display screen in order to follow a target.

The feedback (visual, tactile, auditory or any other kind) provided by the interface is also important as it is an acknowledgment that the action of a user has triggered a reaction in the system and it is part of the communication cycle.

ISO 9241-9 provides methods of measurement of the normative requirements included in the standard like for example pointer movements, maintainability or event feedback. Three types of measurement are described:

- Direct measurement: a measurement that needs a tool or instrument to quantify features.

- Direct observation: the perception or notation of specific features or characteristics of the input device by one or more independent observers. It normally results in a Yes or No answer depending on the observation of the presence or absence of the feature.

- Performance test: a method which determines the match between specified requirements and the corresponding features of an input device. If a performance test is carried out, the experiment design methodology, analysis and results should be provided.

Efficiency and effectiveness for input devices can be tested using the test procedures included in the annexes of the standard. The evaluation process tests the following task primitives: pointing, selecting, dragging, tracing and free-hand input. Not all the task primitives have to be analyzed for all input devices or systems. Only the considered essential components for the system to carry out will be under inspection. The tests provide a measure of throughput. The potential tests to study the performance of the users are: one-direction (horizontal) tapping, multi-directional tapping, dragging, free-hand tracing (drawing), free-hand input (hand-written characters or pictures) and grasp and park (homing/device switching). The tasks selected for testing should be determined by the intended use of the device with a particular user population. In detail, the most used test found in the literature review is the tapping test for evaluating pointing devices:

- Tapping test: the standard describes one-direction and multi-directional tapping tasks in order to evaluate a pointing movement along one axis or in many different directions. The one-direction tapping test consists in two rectangles of width w and a centre-to-centre distance d, see Fig. 2.23. The task is to point and click, along one axis, within each rectangle n times. The test starts when the user first moves the cursor into a rectangle and actuates an event. The test has to be carried out several times with different difficulties, modifying the target distance d and target width w.

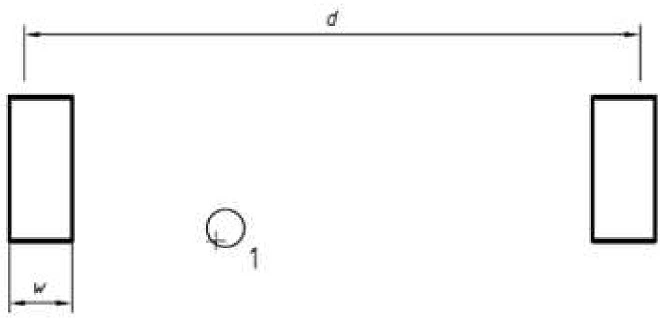


Figure 2.23: One-direction tapping task.

  The multi-directional tapping test is a circle with sequentially numbered targets equally spaced around the circle's circumference. The targets should be arranged so that the movements are nearly equal to the diameter of the circle. The test session starts after the user points to the topmost target and ends when the sequence is completed, see Fig. 2.24. The test should be conducted with different difficulties, varying the size of the circle.

The most common evaluation measures are speed and accuracy. Speed is usually reported with the movement time (MT) and accuracy is usually reported as an error rate, the percentage of selections done outside the target. But these two measures can be put together in the throughput measure.

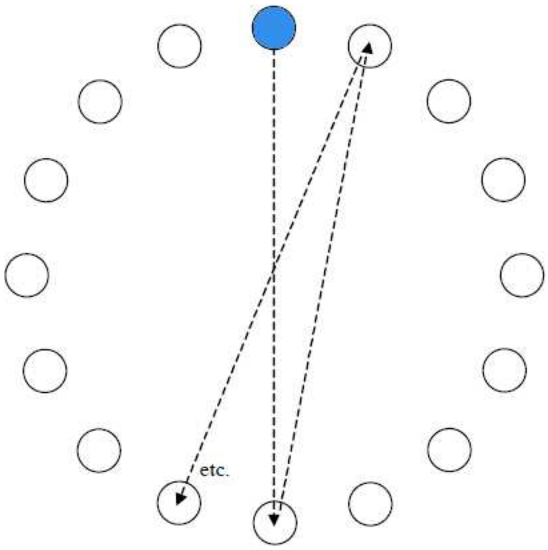


Figure 2.24: Multi-directional tapping task.

Although Fitts' law [31] was established quite a long time ago, it is still in much use as an evaluation tool in human-computer interaction and its power is based on its capability to provide performance comparisons among pointing devices independent of the tasks by unifying speed and performance as throughput. The throughput is the principal calculation for selecting, pointing, dragging and tracing. Throughput, in bits per second, is a composite measure derived from both the speed and accuracy in responses. Specifically, it is calculated as shown in the Eq. (2.1).

$$Throughput = \frac{ID_e}{MT} \tag{2.1}$$

where MT is the average movement time in seconds, calculated from the initiation of movement of the input device to the target selection for n trials within the same condition and ID_e is the effective index of difficulty for a movement task.

ID_e is a measure in bits of the user precision achieved in accomplishing a task expressed as shown in the Eq. (2.2)

$$ID_e = \log \frac{A_e}{W_e} + 1 \tag{2.2}$$

where A_e is the effective movement amplitude and W_e is the effective target width of the displayed target, that is, it is the width of the distribution of selection coordinates computed over a sequence of trials. These two factors are defined in Eq. (2.3) and Eq. (2.4).

$$A_e = \frac{\sum_{i=1}^{n} D_i}{n} \tag{2.3}$$

$$W_e = 4.133 \cdot SD \tag{2.4}$$

where D_i is the translated distance of the *i-th* trial and SD is the standard deviation in the selection coordinates measured along the axis of approach to the target. In the 1D tapping task, Di is the absolute difference in x-coordinates; in the 2D tapping task, Di is the Euclidean planar distance. The coefficient 4.133 in Eq.(2.4) corresponds to a nominal error rate of 4%. In other words, W_e covers 96% of spatial distribution of response points.

The Index of Performance (IP) in Eq.(2.2) uses the effective width instead of the the measured size of the target. Using the effective width takes the variability observed of human performance into account and includes both speed and accuracy [61].

Throughput can give us a measure to compare performance among different devices and users, but it cannot tell us why those differences exist. To try to explain the throughput differences we can study and analyze the paths carried out by the user using a particular device, therefore new measures have come out to compare differences among devices in precision pointing tasks. In MacKenzies et al work [62] they study the movement path to try to establish the “why” by means of defining seven new measurements. They consider the throughput as a “gross measure” lacking any information on movement during a trial. They consider the path where the user moves the pointer from the initial position directly to the centre of the target as the ideal one and the perfect target selection task is the one where the user moves on the ideal path and presses the device button to select the target, see Fig. 2.25.

Figure 2.25: “Perfect” target selection task.

In practice this is not the normal cursor movement, as variations may occur due to the device, the task, the user’s capabilities or other factors. Seven measurements were defined. Four measures are discrete events and they characterize the pointer path, see Fig. 2.26:

1. Target Re-entry (TRE): a target re-entry occurs when the pointer enters the target region, leaves and then re-enters the target region. For example, users with motor impairments or with little experience using a device can encounter difficulties when trying to select a small target and this fact results in target entries.

2. Task Axis Crossing (TAC): a task axis crossing occurs when the pointer crosses the task axis on the way to the target.

3. Movement Direction Change (MDC): a movement direction change occurs when the pointer is travelling in a direction and changes its direction parallel to the task axis.

4. Orthogonal Direction Change (ODC): an orthogonal direction change occurs when the pointer changes direction perpendicular to the task axis.

Moreover, three continuous measures are defined, see Table 2.2:

5. Movement variability (MV): movement variability is computed from the $x - y$ coordinates of the pointer during a movement task. It represents the extent to which the sample points lie in a straight line along an axis parallel to the task.

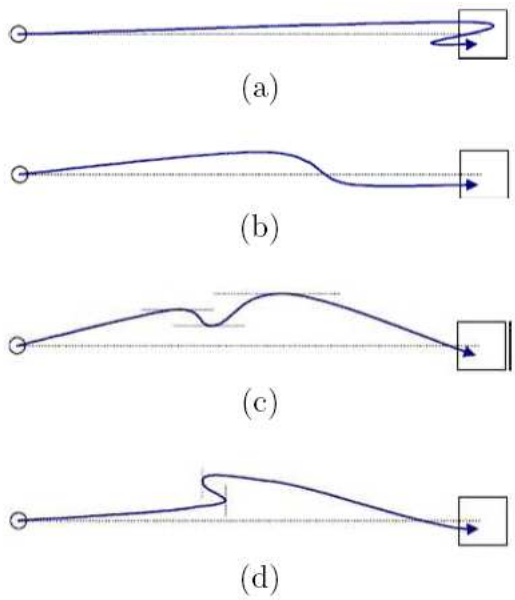


Figure 2.26: MacKenzie et al discrete measures(a) Target re-entry (b)Task axis crossing (c) Movement direction change (d) Orthogonal direction changing.

If we consider the task axis to be $y = 0$, y_i is the distance of the sample point to the task axis, and $\overline{y}$ is the mean distance of the sample points to the task axis. The ideal MV is 0. The MV is computed as the standard deviation in the distances of the sample points from the mean:

$$MV = \sqrt{\frac{\sum (y_i - \overline{y})^2}{n-1}} \tag{2.5}$$

6. Movement Error (ME): movement error is the average deviation of the sample point from the task axis, without taking into account whether the points are above or below the axis. The ideal ME is 0. Assuming the task axis to be $y = 0$ then:

$$ME = \frac{\sum |y_i|}{n} \tag{2.6}$$

7. Movement Offset (MO): the movement offset is the mean deviation of sample points from the task axis. Assuming the task axis to be $y = 0$ then:

$$MO = \overline{y} \tag{2.7}$$

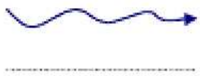
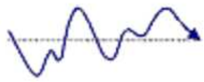
Movement Responses				
				
MV	Low	Low	High	High
ME	Low	Very High	High	Very High
MO	Low	High	Low	High

Table 2.2: MacKenzie's continuous measurements [62].

Furthermore, users with motor impairments often find difficulties with an accurate control of standard pointing devices [108] so the measures used for users with no disabilities may need to be investigated [54] in order to extend or reduce them [55, 67]. Keates et al [53] add another measurement as they observed that users with motion difficulties have problems clicking accurately on a target:

8. Missed click (CL): a missed click occurs when a button click is registered outside the target region.

Chapter 3

SINA project: Development of a hands-free interface for computer accessibility

The technology has to adapt to the user, not the user to the technology.
Aspace therapists

In this chapter we will describe technical information and the design and development process used to achieve a hands-free interface based in computer vision techniques. In Chapter 2, we reviewed different input devices that motor disabled (and non disabled) people could use in order to interact with a computer. In this reseacrh we focus on interfaces that involve computer vision for replacing the standard pointing device. This first section will detail exhaustively these kinds of interfaces.

3.1 Vision-based interfaces

In human to human interaction, visual information is very important and contributes to a richer interaction. Of all the communication channels through where interface information can travel, the visual channel can provide a lot of information that can be used for detection and recognition of human's actions and gestures, which can be analyzed and applied to interaction purposes. This information is captured and processed by means of computer vision. If an interface uses visual information as an input to the system in a HCI context, the result is a vision-based interface (VBI). Vision-based interfaces sense and perceive the user and his actions. The analysis and recognition of human motion and gestures in real-time can be very useful in a wide range of applications, from interacting with videogames to navigating in virtual reality worlds.

In human-computer interaction, difficulties using computer vision techniques arise due to lighting, noise, human appearance variety (physical and emotional such as their face expression) or cluttered backgrounds with possible other moving objects out of our study. It is very important to extract only relevant data from the overloaded visual information as a human eye would do in order to concentrate all the computational efforts in achieving the correct results of the analysis.

Nowadays, computer resources and cameras have reduced greatly in cost and augmented in capabilities, making it feasible to think the use of visual information as a mean to communicate a person with a computer or with any other device that has a camera embedded (PDAs, hand phones ...) or that has the capability of connecting one.

An important advantage of human-computer interaction using computer vision is the non-intrusiveness on the user, that is, no special suit, cumbersome device or sensor is needed on the user, therefore it does not limit the body motion of the user and it offers the possibility of interacting with natural gestures, poses of face expressions.

When using gestures or body motion for interacting, VBI focus on a set of tasks that aim to detect and track or recognise a body part, whether it is the face, the hand, the eyes or any other body part [109, 88] . Let us first define these concepts.

The *detection* of a body part is to determine a binary output that means body part present or not. Usually the *localization* of the body part in the image is also given. *Tracking* means to locate objects and report their changing pose over time. Tracking can be considered as a repeated frame-by-frame detection of an object, so usually implies more than discontinuous processing. To try to improve the tracking and add a temporal continuity and a prediction for limiting the space of possible solutions and speed up the processing, filters to model the object's temporal progression can be used such as line regression or Kalman filters.

Recognition or *identification* involves comparing an input image to a set of models in a database, resulting in confidence scores and probabilities that define how closely the image data fits each model. *Detection* is sometimes called *recognition*, because if there are different kind of objects in the image, one of them has to be recognized. A special case of recognition is *verification* or *authentication*, which judges whether the input data belongs to one particular identity with very high confidence.

We can look for postures or gestures. A *posture* is a static configuration of the human body such as sitting. Gestures are dynamic motions of the body or body parts and can be considered as temporally consecutive sequences of postures. Facial *gestures* are also called facial expressions and their recognition first goes through the step of detecting and tracking facial features.

An object's *appearance* describes its colour and brightness properties at every point on its surface. The appearance of an object takes into account the texture, surface structure, lighting and view direction. These attributes are view-dependent; therefore it will only make sense to talk about them from a given point.

Applying these techniques, a VBI can act as a pointing device in order to communicate the user with the computer. These interfaces may be suitable for physically impaired users. Specifically, for users with hand and arm motion deficiency which cannot use in an effective or comfortable manner the more normalized access devices.

When a person is sitting in front of a computer, the head and the face can be assumed to be visible to a webcam, a very common input device nowadays, or any other image capture device. It is natural to think of a hands-free interface based on eye or head movements or face gestures using computer vision techniques in order to process the images provided from the camera.

In this case, we add more difficulties to the computer vision processing. We have to deal with in-plane (tilted head, upside down) and out-of-plane (frontal view, side view) rotations of the head, facial hair, glasses and users' variability.

If a user is able to move his neck, and has a minimum head control, then head or face tracking is a good approach for a VBI. In the following lines, we will review and consider only those systems that use low cost cameras, in particular USB webcams.

Early works that approached the idea of using computer vision techniques in order to obtain a hands-free interface were general systems with different applications, among them cursor's control [106]. They were automatic head tracking systems that analyzed characteristic facial cues such as colour distributions, head geometry or head motion [13, 106]. As we will see later, it is totally different when we are designing a device for a determined group of users than when we use a developed system for a possible task. The ideal would be when we design a system for disabled users is to take them into account during the whole development process as usability engineering recommends. Betke et al's [10] work was one of the first systems designed and developed for mouse replacement in order to use it with disabled users. Their Camera Mouse locates visible body parts such as fingers of features on the face such as eyes, nose and mouth, and then tracks face movement by searching for similar looking regions in subsequent frames. The searching process is based on the appearance of facial regions. However, in their system, the user or someone must manually select a feature to track. The importance of this work is its contribution of using computer vision technology in order to assist users with disabilities.

Another example of head location estimation by means of facial feature tracking can be found in Gorodnichy et al.'s work [38]. In this case, the goal is to track the nose, whose main characteristic is that, it extends in front of the face and ends with a somewhat universal rounded shape. They identify and detect it as the user moves. The head position is estimated using the offset of the nose from a head centre point. The initialization process and the steps to be taken by the user before starting the tracking process are not clearly explained in the above mentioned work. Once more, the system was not born for disabled users as it is commented that it can be for playing videogames or navigating in virtual 3D worlds.

De Silva et al [103] system was a modification of a face tracking system they had. It was not born neither for disabled users. They search for the eyes first by blink detection and then, they detect the convexity of the tip of the nose like Gorodnichy to track it.

Perini et al [81] FaceMouse was designed for people with severe disabilities, specifically tetraplegic people and as Betke's system, the user has to select manually the feature to track as it is flexible and does not necessary need to track features within the face. A contribution of this system is the idea of the "derivative paradigm". The user indicates the direction along which the mouse movement is directed opposite to the "pointer paradigm" where the user indicates the point on the screen. They use a graphical direction board in order to execute the different movements. It works like a joystick.

Hannuksela et al [42] extract facial features automatically by combining skin detection, gray-scale morphology and a geometrical face model. Then they use Kalman filtering to estimate the 3D pose of the moving head and they track the facial features. To control the interaction they roughly detect the gaze direction by the orientation of the head. They consider the direction of the gaze as the normal defined by three facial features: the mouth and the centres of the eyes.

Other systems that have been designed for disabled users [27, 79] lack of studies with their intended users. It is technology specifically designed as a hands-free system in order to replace the standard mouse for users with mobility impairments in the upper extremities but in the designing process there is no mention in their papers of the participation of this kind of users.

Morris and Chauhan [71] have not used their system on motor impaired users, but their research work makes an analysis of the difficulties caused by using webcams taking into consideration problems such as low image resolution and bad image quality. However, in order to function in any environment, their system needs a previous calibration stage to establish several process parameters.

Kjeldsen [56] presents an cursor position control system that takes the dynamics of human motion into account to give smoother and more responsive motion estimation. Nevertheless, it also requires a phase of predefined user's movements before the head tracking process starts. This calibration phase requires a level of head control that in certain kinds of disabilities is not possible. They started testing the interface with cerebral palsy and spinal cord users.

In Mauri et al [66] no technical information is detailed, but they present a hands-free interface study with disabled users. In [67] they present a possible framework to evaluate the usability and/or accessibility, although they have not started with the field work.

All the research work reviewed were presented in conference and journals papers, although there are also commercial solutions where no technical information is provided such as EyeTwig Tracker [28] for 270 dollars or QualiEye [91] for 275 dollars.

3.2 Considerations of a hands-free interface

First of all, we classify the VBI using Hinckley's [45] parameters:

- Property sensed: in vision-based interfaces, image processing is used. The property sensed is a visual property such as colour or when working with n frames, it could be the motion between a frame and another one.
- Number of degrees: when working with VBI, with one only camera, we work with two dimensions.
- Indirect versus direct input device: VBI are indirect, as they do not have direct contact with the system's screen.

When a body part is used as a pointing device, three processes have to be carried out successfully: the correct detection of the body part, its accurate tracking and finally the translation of the tracking data into the cursor's position. All three steps are important in order to provide a satisfactory performance of the cursor's movement and avoid distressing the user. In particular, when thinking in a head or face mouse using computer vision, we have several design decisions to take to achieve a usable device:

- Decisions on the user: we have to decide if we are going to detect the user automatically or if the user is going to assist in his detection. Also, we have to select a body part of the user to track.

- Decision on the interaction: we have to decide issues such how the control of the cursor is going to be, the interaction's feedback for the user and if the tracking process fails, how is the interface going to recover.

In following lines we will analyze this design issues.

3.2.1 Region to track

We have to decide which part of the user is going to be tracked. This will be strongly dependent on the user's capabilities, whether he has head control or not. On the one hand, if the user cannot move his head in a controlled manner, then eye tracking could be an option. In the other hand, if he can control the neck and head we can use the option of selecting a face feature/s [10, 35, 42] or the overall head motion for tracking [13, 106, 79]. When working with motor disabled users, it is sometimes desirable the approach of using the face or head motion for access even if his head control is not perfect in order to exploit as maximum his capabilities for rehabilitation purposes.

If we use features, instead of the overall head or face, then we can select different features in the face. Most of the systems use or recommend the nose (or nostrils) as tracking feature due to several reasons. Kjeldsen [56] does not track the nose directly, instead he tracks the user's face, but the pointer moves to approximately where the user's nose is pointing. Morris and Chauhan [71] and El-Afifi [27] choose to track the user's nostrils and use their position to define the head pose. They mention two advantages in using nostrils: they are clearly separated from any other features that could be confused with them and they are relatively small and situated away from the face boundary, this means that they remain visible even under extreme facial poses. Betke et al [10] and Gorodnichy [35] find the nose a desirable feature because it is easy for a computer user to point his or her nose in a particular direction while watching the screen, it is in the center of the face and does not become occluded when the user's head moves significantly. In most of the user's head movements the nose is visible, even when scaling, rotating or translating. The nose tends to contain a good amount of brightness contrast to surrounding features and therefore making it easier to find points or zones to track. And it is not occluded with beards, moustaches or glasses.

Betke et al [10] also studied eye tracking with their system; they tracked the whole eye, not only the pupil, using the brightness contrast between white eye sclera and dark iris and pupil, along with the texture of the eyelid. It was not successful because it is a relatively difficult feature to move while viewing the screen and rotating the head may cause occlusions. Lip tracking is also possible with their system because of the brightness difference between the lip and the cleft. Perini et al's [81] system also allows the use of different features but they recommend the nose.

Hannuksela et al [42] don't track just one face feature, they make a combination of head and facial features tracking. They find the head and then they use three facial features: the mouth and the centres of the eyes for creating a constellation.

3.2.2 Initial user detection

The detection of the body part can be done using three different approaches. The first one is when someone manually selects the body part, like for example selecting an area bounding the body part with the standard mouse. This method needs the assistance of another person if the user is not able to select the body part on the image.

The second approach is an automatic body part location by means of computer vision techniques. Many of the vision-based systems used nowadays base their location in detecting skin colour. Problems can come from environmental conditions such as lighting or having similar colours in the image. Automatic location can also use classifiers. A classifier is a method of classifying inputs into defined output categories and it is trained to distinguish the inputs. These kind of automatic systems are reliable if environmental conditions are favourable.

The third approach is a method based on a user's signal for the tracking to start. For example in Kjeldsen [56], the user tips his head three times and then pauses, when this happens, the system centres a small window on the screen saying "Aim here" and the user has to aim his head at the centre of the screen.

The easiest approach for the user is a totally automatic system, although different interfaces add a calibration phase before starting to work with the hands-free interface [71, 56]. As we are talking about users whose physical capabilities are limited, the initialization phase should be minimal and it is desirable that no one else is involved. Avoiding the calibration phase, the system is faster and easier to operate by the user but we loose information about the screen's size and other factors.

3.2.3 Tracking

In order to use body parts' motion to interact in a human-computer context, we have to achieve a way of tracking the movements. Motion flow has to be controlled and it is computed by matching a region from one frame to a region of the same size in the following frame. The motion vector for the region centre is defined as the best match in term of some distance measure. Two methods can be used to control the motion flow:

- Region based tracking: the idea in region or blob-based tracking is to identify connected regions of the image, blobs, associated with a particular object. Regions are often obtained through background subtraction or by colour based methods and then they are tracked over time using the information provided by the entire region (motion, size, colour, shape, texture or centroids).

- Feature based tracking: this method abandons the idea of tracking objects as a whole, but instead tracks features such as distinguishable points or lines on the object. Even in the presence of partial occlusion, some of the features of the moving object remain visible, so it may overcome the problem.

When the control of the motion flow uses the approach of feature based tracking, it is important to select the best features. A good selection of features in an image is one of the main keys for carrying out a good tracking. The most suitable features to track are selected due to a set of properties:

- Distinction: it means that a point must be different from its immediate neighbours. This will avoid the aperture problem, that is, the selection of points belonging to uniform areas or lines.

- Uniqueness: it means that the feature can be identified globally, that is, the ideal is a feature not to look like anything else in the image. Therefore although a feature is locally distinguishable, if it appears in several parts of the image, this feature should be rejected.

- Invariance of a feature: it means that the appearance of a point should not change due to geometrical distortions, motion or lighting.

- Stability: it means that the appearance of a point should be invariant in reference to a point of view. Selected points should correspond to points of interest of an object and not intersections among objects or objects with the background.

3.2.4 Position mapping

We have to translate the tracking data into the cursor's position. This translation is called the transfer function. The vision-based interface should provide a mapping function ϕ, which maps the user parameters $\vec{u}$ to the cursor parameters $\vec{c}$ at every time stamp t, see Eq(3.1).

$$\phi : \vec{u}_t \rightarrow \vec{c}_t \tag{3.1}$$

where the user coordinates are the Euclidian coordinates of the user's body part used to control the cursor, $\vec{u} = \{x, y, z\}$ if the 3D position of the body part is used, taking into account that we will need at least two calibrated cameras for obtaining the triangulation. And $\vec{u} = \{x, y\}$ if we are using a 2D position of the body part in an image provided by only one camera; the cursor coordinates are the ones on the screen: $\vec{c} = \{i, j\}$.

Two different approaches can be taken to translate the motion in the image to the position in the system: relative or absolute positioning. The relative positioning means that the VBI reports the change in coordinates instead of reporting the current coordinates of the device, the given location is relative to the previous location, rather than relative to a fixed origin [10, 42, 81, 79]. On the other hand, the absolute positioning has an origin location and works as a reference [56, 71].

In addition we can find two different ways of working. The first one would be to translate positions as mice do and the other system would be to work as a joystick. The mouse mode attempts to simulate the actual mouse: offsetting the nose from the centre position causes the cursor to move in a similar direction [71, 66, 10, 79]. When working in the joystick mode, the offset from the centre causes the mouse's cursor to move in a similar direction, but going back to the centre zone, stops the movement. The speed of the cursor is determined by the offset's amount. Several systems allow switching between both modes [38, 81].

3.2.5 Feedback

We have to take into account the absence of "touch" when using a VBI. As the user is not touching any physical device, as he does when he uses a mouse or a joystick, he looses the feedback connection. In general user interaction design, Norman [74] suggests that a correct closed-loop feedback goes together with intuitive interfaces. In interfaces based in computer vision, as described in Gorodnichy [37], "One has to realize that, unlike hands-operated interfaces, hands-free interfaces do not have a feedback connection. By holding a mouse, a user not only controls the program, but s/he also keeps the knowledge of where the mouse is. No matter how robust the perceptual user interface is, it can lose the user; it might be even more appropriate to say that a user loses the interface".

In most of the reviewed hands-free systems in order to achieve the feedback connection, they rely on showing a window with the computer vision process [10, 91], others don't show any image [66] and others like Gorodnichy [37] choose a flying mini-videoimage, a 32×32 pixel box, with the processing information state.

In addition to the feedback that the system has to offer of the processing, it is important to know always the state of the interface like which event is selected in order to allow the user to act accordingly. It is obvious that an interface that has to carry out the interaction between the computer and the user and works as a pointing device has to respond in real-time. Real-time in this case means that the user is not aware of a delay between his action and the system's reaction.

3.2.6 Reboot

Hands-free interfaces based in computer vision techniques can sometimes track or detect incorrectly the user due to changes in lightning, user's relative head position, user's fast movements or because the detection and tracking algorithm is not robust enough. When this occurs, the system should react and recover automatically or it will show the calibration phase or a restart module. Usually, when the system can work with different body parts, the process of selecting it restarts. It is desirable that the process to recover these errors is automatic, avoiding the need of a person to assist the disabled user.

3.2.7 Event execution

Different ways of activating the events are possible. First of all, these systems can go accompanied with an external switch or any other device to carry out the mouse's events. Most of the systems work with "dwell", that is, the stop-and-click way of working. There is a event toolbar and the user has to keep the cursor on the event a predefined amount of time, this event is selected; to execute it, the user has to carry out similar action on the screen element [10]. Other systems use blink detection or face gestures [36, 79, 103] or sounds [66].

3.3 Hands-free interface: the first prototype

After reviewing the considerations to take into account for hands-free interfaces based in computer vision, in this section, we describe the first prototype of our hands-free interface. Later we will explain the improvements done to this prototype when considering usability. A standard USB webcam is used for image acquisition, providing a low cost system. The user's work environment conditions are normal (office, house or indoor environments) with no special lighting or static background. The use of attachments or stickers on the user's head is not necessary. The only system's requirement is that, at the beginning, users must position their head facing the screen avoiding any type of orientation. By positioning their head in pan, tilt or roll angles, they may cause the failure of the automatic face and facial features initial detection. Nevertheless, once the system is initialized it works correctly for head orientations (providing that facial features are visible). Moreover, the system's feedback is in real-time and is precise and robust.

To achieve an easy and user friendly user interface, the system is composed of two main modules: Initialization and Processing, see Fig. 3.1. The Initialization module is a totally automatic learning phase, responsible for extracting the user's distinctive facial features. It detects the user's face and the best features over the nose region to track. If all features get lost, then the interface searches for the user face and his features again. The first approach was to involve the user in a calibration phase to analyze the relationship among the physical screen size, the image captured by the webcam and the user's head motion range. A first test with real users made us back up this idea, as the users found it complicated to understand. The Processing module tracks the features and sends the position and event to the system for placing the cursor.

The point that is used to map the position of the head to the position of the cursor is the average of all the features found in the nose region. The mouse's events are carried out by means of a graphical event toolbar and the way to select a desired event is by stop-and-click, that is, position the cursor on the event button and stay on it for a particular number of frames. For executing the event, similar action is needed on the element we want to activate.

In the following lines, we will explain the subprocesses carried out in these two general modules.

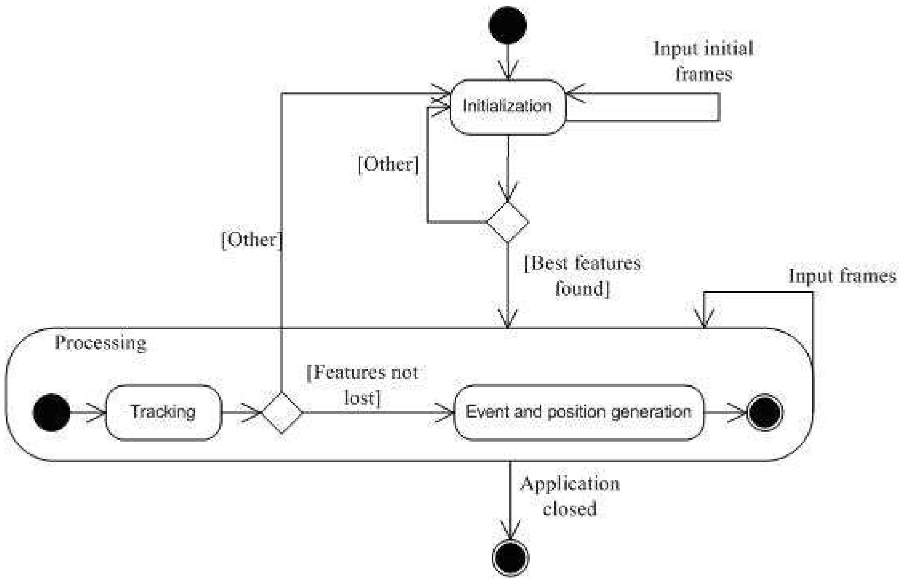


Figure 3.1: UML-like diagram of the system.

3.3.1 Face and Facial Features Detection

It is very important for an interface to be as natural as possible and to hardly involve the user in the initialization; consequently, it shouldn't require any calibration process where the user interferes. To accomplish this requirement, it is useful an automatic detection of the face by means of a real-time face detection algorithm [112].

In our case, the user should just stay steady for a few frames for the process to be initialized. The face detection is considered robust when during a few frames the face region is detected without great changes in its position. Then, it is possible to define the initial user's face region to start the search of the user's facial features. Based on anthropometrical measurements, the face region can be divided in three sections: eyes and eyebrows, nose, and mouth region, see Fig. 3.2.

We decided to select the nose as the feature to track, because is almost always visible in all positions of the head facing the screen and it is not occluded by beards, moustaches or glasses [35]. Over the nose region, which is found in approximately the second third of the face, we look for those points that can be easily tracked,

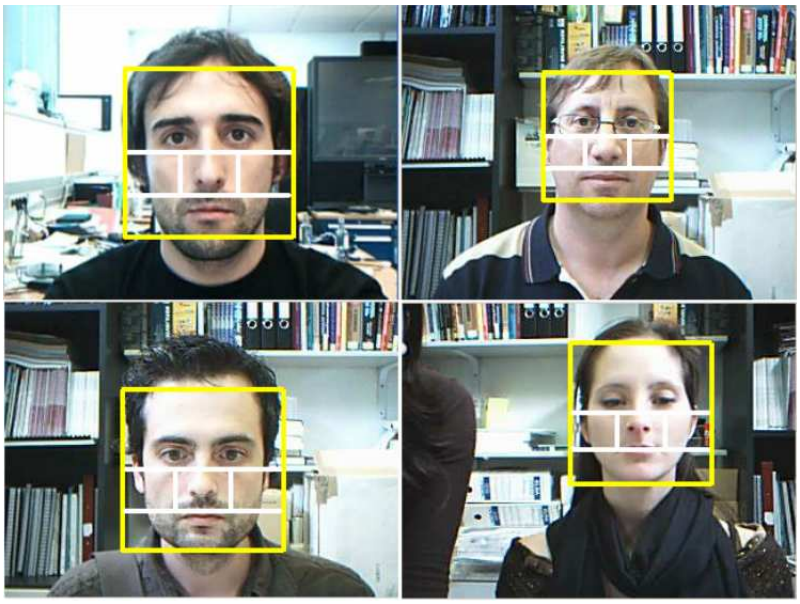


Figure 3.2: Face division: eyes and eyebrows, nose and mouth.

that is, those whose derivative energy perpendicular to the prominent direction is above a threshold [101]. This algorithm theoretically selects the nose corners or the nostrils. However, the ambient lighting can cause the selection of points that are not placed over the desired positions such as shadows; this fact is clearly visible in Fig. 3.3(b). Ideally the desired selected points should be at both sides of the nose and with certain symmetrical conditions.

An enhancement and a re-selection of the found features must be carried out having into account symmetrical constraints. Figure 3.3(c) shows the selected pairs of features that are considered due to their symmetry respect to the vertical axis. This reselection process will achieve the best features to track and it will contribute to the tracking robustness. Figure 3.3(d) illustrates the final point considered to map it to the system, that is, the average point of all the final selected features that will be centred on the nose.

The nose detection process has been evaluated using the BioID face database. We have chosen this database because the image resolution and acquisition conditions

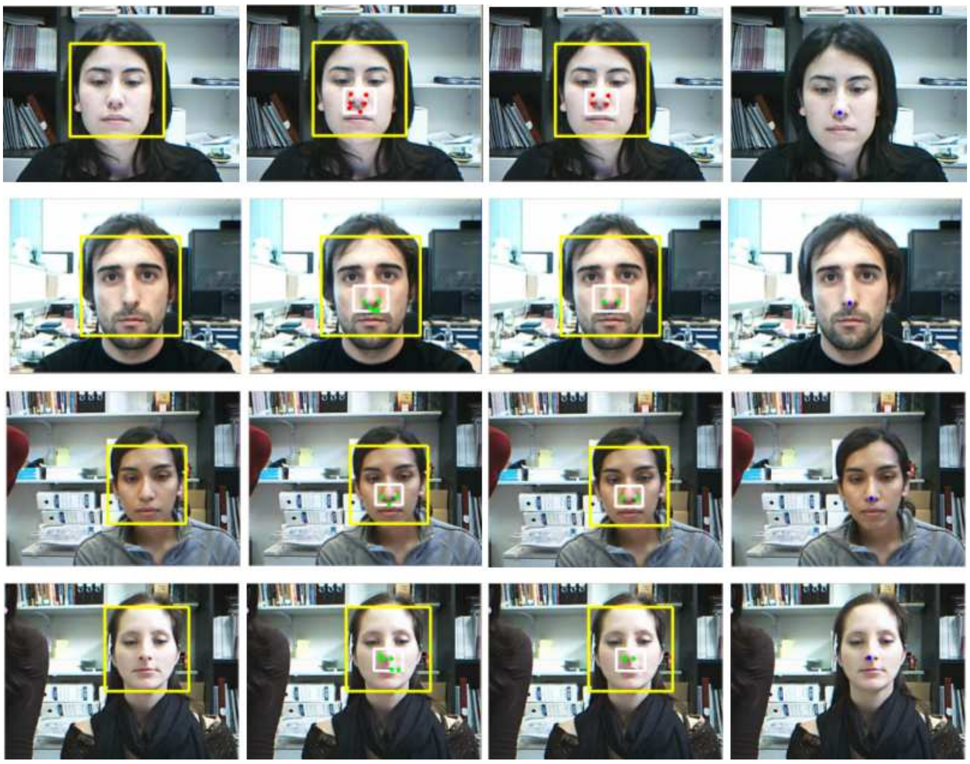


Figure 3.3: (a) Automatic face detection. (b) Initial set of features. (c) Best feature selection using symmetrical constraints. (d) Mean of al features: nose point.

are similar to the ones belonging to our application. The BioID is a head-and-shoulder image face database that stresses "real world" conditions featuring a large variety of illumination and face sizes with complex backgrounds in normal conditions with no restrictions. The database consists of 1521 frontal view images of 23 different test persons with a resolution of 384 × 286 pixel [51]. Tests conducted with these images have shown that 95.79% of faces are successfully detected, and among the detected faces about 96.08% of nose features are detected with enough precision. In order to measure the precision of detection, we take advantage of the fact that the database images have manually annotated several facial feature points (http://www.bioid.com/downloads/facedb/index.php). Specifically, we use the "tip of the nose" mark for comparison with the results of our nose detection algorithm. The precision was measured computing distance between the mean of the features and the "tip of the nose" mark. The computed distance is the root squared difference between the two points. In addition, we also have computed the differences in X and Y. Precision results are summarized in Table 3.1.

Displacement	Mean	Standard dev.	Maximum	Minimum
Total	6.03	4.66	29.95	0.03
Horizontal	2.34	2.05	15.79	0.00
Vertical	4.98	4.86	29.43	0.00

Table 3.1: Precision results of the nose detection process (in pixels).

Note that errors in face detection are due to incorrect placements of the head in the image which result in incomplete visibility in the image, see Fig. 3.4(a). Besides, errors in the nose detection are mainly due to lighting conditions that lead to different brightness on either side of the face. This causes that the feature selection algorithm cannot find symmetrical features, see Fig. 3.4(b).

In relation to the precision of nose detection in Table 3.1 we can see that error in Y is greater than error in X. This is caused by the fact that symmetrical features are detected in most cases near the nostrils; therefore the mean of found features is properly located horizontally but with a little displacement in the Y axis towards the low part of the nose. Nevertheless, taking the acquisition conditions of the database

Figure 3.4: BioID database samples showing the main causes of detection errors for face (a) and nose (b).

images and the computed displacements into account, we can conclude that the precision of the presented nose detection process is acceptable for our purposes.

3.3.2 Facial features tracking

The important positional results for the interface are reported by the nose tracking algorithm, where we use the selected features of the nose region. In this case, the spatial intensity gradient information of the images is used for finding the best image registration [5]. As it was mentioned before, for each frame the mean of all features is computed and it is defined as the nose position for that frame. The tracking algorithm is robust for handling rotation, scaling and shearing, so the user can move in a more unrestricted way, see Fig. 3.5, but again lighting or fast movements can cause the lost or displacement of the features to track. As only the features beneath the nose region are in the region of interest, a feature will be discarded when the length between this feature and the mean position, the nose position, is greater than a predefined value.

It is important to point out that the system is able to react when the features get lost, detecting when it occurs and restarting automatically the system calling to the Initialization module.

Figure 3.5: Head motion range.

3.3.3 Replacing the traditional mouse

By means of the nose tracking process, the user can control the cursor. The precision required should be sufficient for controlling the cursor to the desired position. As mentioned previously, we can use two approaches to map the nose point to the cursor's position: absolute and relative. In the absolute type, the position would be mapped directly onto the screen, but this approach requires a very accurate tracking, since a small tracking error in the image would be magnified on the screen. Therefore, it is used relative motion for controlling the mouse's motion, which is not so sensitive to the tracking accuracy, since the cursor is controlled by the relative motion of the nose in the image. When the user wants to move the mouse position to a particular place, there is a tendency in the direction of the movement.

The relative type yields smoother movements of the cursor, due to the non-magnification of the tracking error. Then, if $\vec{u}_t = (x_t, y_t)$ is the new nose tracked position for the frame t, to compute the new cursor's coordinates, $\vec{c}_t$, we apply Eq.(3.2)

$$\vec{c}_t = \vec{c}_{t-1} + \alpha(\vec{u}_t - \vec{u}_{t-1}) \tag{3.2}$$

where α is a predefined constant that depends on the screen size and the user's head motion and translates the image coordinates to cursor coordinates. The computed mouse screen coordinates are sent to the system as real mouse inputs to place the cursor on the desired position. In theory, it would be possible to use Kalman filters to smooth the positions. However, Kalman filters are not suited in this case because they don't achieve good results with erratic movements such as the ones performed by our users' face motion [29]. Therefore, our smoothing algorithm is based in the motion's tendency of the nose positions (head motion). A linear regression method is applied to a number of tracked nose positions through consecutive frames. The computed nose points of n consecutive frames are adjusted to a line, and therefore the nose motion can be carried out over that line direction. To avoide discontinuities the regression line is adjusted with every new point that arrives.

The mouse's events are carried out by means of a graphical text-event toolbar, see Fig. 3.6, and the way for selecting a desired event is by wait-and-click, that is, position the cursor on the event button and stay on it for a particular number of frames. To execute the event, similar action is needed. Later we will describe the evolution of the text-event toolbar.

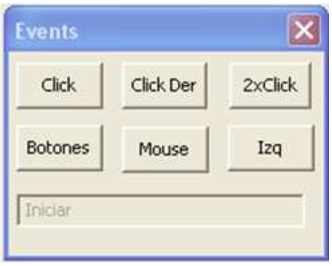


Figure 3.6: Mouse events.

The events presented are the most usual actions that a person can perform using a conventional mouse. These are: left click, double left click, right click, dragging function and disable all the buttons.

3.4 SINA Project: development of the hands-free interface

The main aim of this project was to design and develop a really useful and usable hands-free interface in order to achieve an input device for users with motor impairments. The group of people participating in the project were professionals coming from different backgrounds and disciplines such as human factors, special education, education technology, occupational therapy and computer science.

Taking advantage of the vision-based interfaces and knowing that technology is an important component in the integration of people with disabilities into society [17], we developed the hands-free interface, SINA, presented previously.

The project had two phases: a designing and developing phase, where end-users were included to test and refine different prototypes; and a second phase, where we evaluated the final system.

When we first started with this project, few hands-free systems with no infrared lightning based in computer vision existed. As mentioned before, not all the systems were born to offer accessibility to disabled users [13, 106, 38]. The ideal is that when we are designing a system for disabled users is to take them into account during the whole development process. It is demonstrated that the lack of usefulness and usability can cause the user to abandon the use of an assistive device [98, 93, 94]. Betke et al [10] was one of the first systems designed and developed for mouse replacement in order to use it with disabled users. After these initial vision-based interfaces, others came and they were developed parallel to our system or later [81, 79, 71, 56, 66].

However, in these works, they do not explain the process followed when developing the systems and how end-users and evaluators have influenced the interface design. Frequently, the process followed when developing a system is the one defined in software engineering. Although, when designing and developing a product and especially if disabled people are the end-users, software engineering is not enough. Usability and accessibility must be taken into account in early stages of the development.

In the development of the hands-free interface for motor disabled users we have used a traditional software engineering process. In particular we have developed the system using a prototyping system to include usability to comply with Gould and Lewis [39] principles when designing for usability: early focus on users and tasks, empirical and experimental studies with simulations or prototypes and iterative design.

Prototyping is especially good for designing good human-computer interfaces. “One of the most productive uses of rapid prototyping to date has been as a tool for iterative user requirements engineering and human-computer interface design” [78], but requires at first sight more time and effort than other approaches. Few initial requirements were demanded at first.

- **R1.** The system has to be non invasive: the system has to work with no sensors, no cables, no stickers or any other element on the user. Users should feel comfortable.

- **R2.** The system has to be low cost: the software should be free for the end-user and the overall system must be low cost, as we can find commercial products like eyetrackers that can cost few thousands of euros.

- **R3.** The system has to work with the user's head movement: the system has to work by moving the head or the face. Our end-users are people whose upper limbs are not functional enough to work effectively with a mouse but they have a minimum head control.

- **R4.** The system has to work in normal environmental conditions: normal here means with cluttered backgrounds and no special light conditions.

Taking into account these initial requirements, we decided to implement a vision-based system which allow us to use a low cost imaging device like a webcam, is not invasive at all and by processing images for extracting the user's head/face movement we can move the cursor. Working with these initial requirements and after reviewing other systems whose aims were similar to our interface, a first prototype was designed. In the following lines, we will describe each phase of the prototyping system. The process of prototyping involves four steps, see Fig. 3.7:

- Identify requirements.

- Prototyping.

- User's review.

- Revise and enhance the prototype.

3.4.1 Identify requirements

This phase is the one in charge of the requirements definition. In this phase a computer science professional with motor impairments helped in the requirements analysis. This user usually works with a trackball but has tested different interaction systems. To the initial four requirements, we added the next ones:

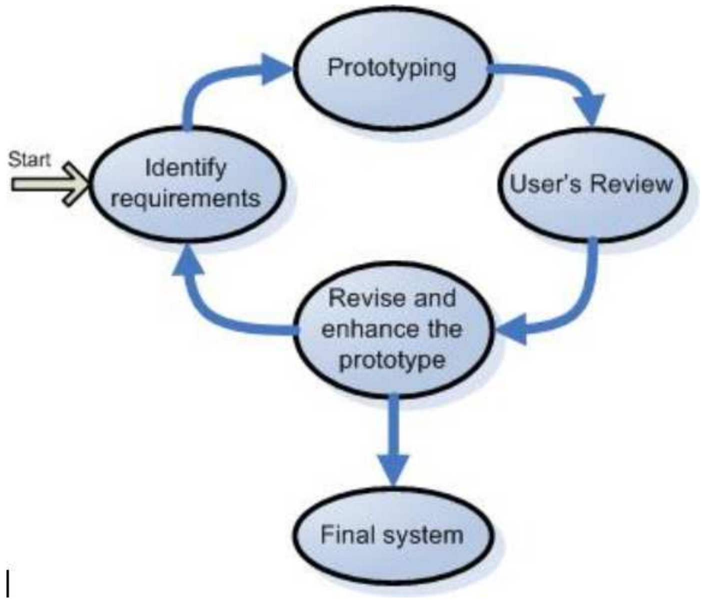


Figure 3.7: Prototyping design.

- **R5.** The system has to be able to perform all the mouse's events. A graphical event toolbar will be always visible. The events will be performed by wait-and-click, that is, position the cursor on the event button and stay on it for a particular number of frames. To execute the event, a similar action is needed. The head motion will be transformed into a position of the cursor on the screen.
- **R6.** The position of the webcam has to be flexible. The user's face has to be within the image provided by the webcam, but considering this fact, the webcam can be on the table, on the screen or over any other support.
- **R7.** The system has to be totally automatic. Users should rely as minimum as possible in other people assistance.
- **R8.** The system has to consider the user's head motion range and head control. Users have different range of head motion, therefore the system has to move taking into consideration the head movements that the user can perform. Furthermore, the ability of every user to keep a steady position to perform for

example a mouse event is different; so then, the system should also control this fact.

- **R9.** The image shown in the processing window has to be coherent with the user's motion. It should be a mirror image to avoid confusion to the user.

3.4.2 Prototyping

A first prototype was developed following the recommendations of the computer science professional with motor impairments. The initial requirements were implemented. In the previous section 3.3 the first prototype is detailed. This prototype was evaluated in laboratory conditions and improved before taking it to real scenarios with real-users as we will see in following sections.

3.4.3 User's review

Three different reviews were done in the process of designing and developing the system with disabled and non-disabled users. They have been carried out by different professionals (technical, pedagogical, occupational therapists and human factors experts) involved with the direct implementation of the system and outsider observers with technical and non-technical background. We will explain briefly these tests, although later in Chapter 4 they will be detailed.

The first test was done in laboratory conditions with non-disabled users. This evaluation was intended to prove that the system followed correctly the user and that he would be able to click with enough precision for working. The user had to click at every circle of a 25 target grid and data of errors and distance to the target were saved.

A second test was done by external evaluators from the Automatic Control Department of the Technical University of Catalonia with users with no motor disabilities and in laboratory conditions. This test was carried out by a group totally independent from the SINA project. This evaluation was intended to prove that it was possible to work with the hands-free interface together with an interface representing the control system of a domotic house. Moreover, they applied the GEDIS guide [85] to validate the hands-free interface. The GEDIS guide is the 'ergonomic guide for supervisory control interface design' which covers aspects of the interface design like for example: the interface calibration, the user-oriented graphical toolbar, the head motion range and the feedback in order to improve the effectiveness of human-computer interaction.

The third test was with real end-users, users with cerebral palsy. Cerebral palsy (CP), is a term used to describe a group of chronic conditions affecting body movement and muscle coordination. We evaluated the hands-free interface in ASPACE, a CP centre. The centre is divided in a day care centre for adults and a school (up to 18 years old). In this centre many of their users work with some kind of assistive tool, therefore it was a perfect place to evaluate our interface and to receive the feedback, although we have to consider the cognitive level of the users. Six persons participated and they carried out sessions during 5 months, 20 minutes for the children and 30 minutes for the adults. Users performed from 20 to 26 sessions. All the process was evaluated and monitorized by the therapist and an assistant that filled a spreadsheet in order to register the session.

We obtained two different data from these users: quantitative and qualitative. The test was to observe these users working with the interface in their daily activities with the computer. Users carried out their own tasks, that is, they continued working with their personal educational activities, but incorporating new tasks that before they could not achieve due to their input device. Most of the enhancements done to the final system are due to the feedback of these users and their therapists as they have been using the interface for a long period of time and they present different characteristics to non disabled users. When working with cerebral palsy users, new considerations appear. Improvements will be described in following sections.

3.4.4 Revise and Enhance the Prototype

Based on the feedback of the three tests, new requirements appeared and important recommendations were given in order to improve the prototype. These requirements were analyzed and implemented if the impact on the system was meaningful. Some modifications were small and didn't suppose a great effort programming but it meant a very important key in usability issues. Instead, others required a process of research and therefore they were not so immediate.

To study the impact of the usability on the hands-free interface, we will identify all the new requirements and recommendations using Juristo et al [52] classification. They reviewed and analyzed usability recommendations in the HCI literature such as Nielsen [72], Shneiderman [102] or Preece et al.'s work [90]. They classified these recommendations in three categories depending on their effect on software development: usability recommendations with impact on the development process, usability recommendations with impact on the UI and usability recommendations with impact on design. Attending this criteria, we are going to identify the usability recommendations that applied in our study case and the new requirements that appeared after starting to work with users.

Usability recommendations with impact on the development process

These recommendations are considered if the development process changes, that is modifying techniques, activities or products used during such process. As mentioned, this project was carried out by experts of very different areas; therefore the overall process enriched of the know-how, the techniques and methods used in the diverse disciplines. The mix of professionals contributed to improve the quality of the system and the development process.

We developed the first prototype and evaluated it with non-disabled users to demonstrate the system's functionality specially the accuracy and operability. Only quantitative data was gathered together. The system's was focused on motor disabled users. The experience of the technical group working with disabled users and in our case with cerebral palsy users was null. The pedagogical group, experts in special education and education with technology, put us in contact with the cerebral palsy centre and facilitated the approach. Meetings among the technical, pedagogical and the therapists of the centre were carried out for preparing the process of introducing the interface in the computer sessions. Users to participate in the project were selected, and we planned with great care a action planning, user profile registration (see Annexe B) and a spreadsheet to register each session. This spreadsheet contained information of the physical state of the user that day (state, humour), technical setup (parameters of the hands-free interface, settings of the webcam, settings of the user), the tasks carried out and the difficulties arisen, see Annexe C.

It was essential to work directly with the users' therapists as they know their users [89] and which tasks are more adequate to carry out with the users as all of them have different capabilities. Some only do action/reaction activities, others are able to surf the internet working with a graphical keyboard to write and others are not capable to work yet with the event toolbar.

Furthermore, external evaluators from the Technical University of Catalonia evaluated the interface with control engineering students, that is, users with no disabilities. Diverse experimental tests were carried out using different hands-free interfaces to control a domotic scenario [87]. Based in the results, evaluators wrote a set of design recommendations. Table 3.2 shows in the first column properties of hands-free interfaces, central column describes the recommendations and the third column shows how the developers of the present work have applied these recommendations successfully.

Usability recommendations with impact on the UI

These recommendations affect the user interface, the system's presentation through buttons, pull-down menus, check-boxes, font, colours and all other elements that compose the system's appearance. If the UI is well separated from the core of the software, the cost of modifying the interface design (for example: adding an image to a button or changing the layout of the elements) should not be too high.

The external evaluators from the Technical University of Catalonia used an ergonomic guide for display design, the GEDIS guide, for recovering information on hands free interfaces and in particular they applied it to our system. The GEDIS guide offers design recommendations on existing interfaces or when creating a new

Properties to study in a hands-free interface	External Evaluators: Design Guidelines Software	Developers: Improving the hands-free system
Calibration/Recalibration		
The calibration process is too difficult to understand for very young children. A heavy calibration can influence in the user' satisfaction	Reduce the calibration process at minimum in order to obtain a natural interface	No calibration is needed. The system is totally automatic
It is interesting to practice the use of the interface	Train the user with useful tasks or games	The therapists use computer games (SINA training) and educational tasks
Graphical Toolbar		
A graphical tool bar is more intuitive that a text tool bar	The toolbar must be easy to understand and use	The UI has experienced the change from text to a mouse metaphor for improving the understanding
The navigation inside a text toolbar can be difficult for some users	Improve the location and visibility of the graphical toolbar	The position and visibility has also been enhanced.
Head Movements		
The repetitive head movements of the user can increase the fatigue	It is necessary a correct relationship between the head movement of the user and the pointer movement on screen	There is a profile for adapting it to the user (user's settings).
Some users have reduced head mobility	It is necessary to guarantee a good performance with a low number of head movements	The therapists are studying the use of this interface inside rehabilitation programs.

Table 3.2: Recommendations from the external evaluators.

one. They centred their study on the graphical event toolbar and a set of new recommendations appeared to improve the user interface that take into consideration aspects such location, visibility, size or colour use. All these guidelines have contributed to the redesign of the user interface [86].

The graphical interface has suffered many changes since the first prototype thanks to the feedback of all the tests carried out and in order to present a more natural-mapping [16]. The earliest version was all text, see Fig. 3.8(a), and then the texts on the buttons were replaced by images in order make a metaphor of the real mouse, see Fig. 3.8(b). Finally the hands-free system offers a more aesthetic interface done by a designer, see Fig. 3.9.

- **R10**. The system's event toolbar has to contain images instead of text and they have to be as close as possible to the metaphor of a standard mouse. Images representing the different mouse events have to be meaningful and the user should relate them directly with the mouse's events.

Figure 3.8: Interface (a) Event toolbar with text (b) Event toolbar with images.

There is still a recommendation which has to be applied. The opposite colours theory imply that certain colour combinations must not be used to avoid post-effects

Figure 3.9: Current user interface.

[14]. These post-effects can affect how the user stares at a colour: when looking at red colour during certain time, this colour exhausts, inhibits and green appears. One of these combinations to avoid is blue-yellow.

- **R11.** The system should present a correct use of colours. Colours of the interface should follow eye characteristics and ergonomic and psychological constraints.

Furthermore the initial position of the event toolbar was always on the right side of the screen as normally icons or menus are located starting on the left side of the screen for users that read from left to right direction. Evaluators recommended being able to place the event toolbar in three different positions: right, up and down region.

- **R12.** The system's event toolbar has to adopt different initial positions in order to gain flexibility and adapt itself to the user.

The initial program window where the user could see his image and the cross on his nose (meaning that the system was tracking correctly) kept on the screen until the user hid it. This fact distracted the cerebral palsy users attention as they kept staring their own image. Now, after the face and features to track are detected, this window minimizes. This change didn't suppose a great effort for the developers but it really improved the usability of the interface.

- **R13.** The system's initial window should disappear as soon as the system has located the user's face and features and the head motion has the cursor's control. If the features followed get lost like for example when the user turns his head to talk to the therapist, the window system will automatically appear on screen and the initialization process will take place.

The problem is that feedback on the tracking process is lost when we hide the initial window. It is important to know if the tracking point is displaced or lost. Automatically if all features being tracked (remember that several features around the nose are tracked and the mean of all these points is then mapped to the system) get lost, the initial window will appear on screen. However, if features get displaced due to a fast movement like a spasm or an exaggerated change of light conditions, the user should be aware. In order to receive the feedback from the hands-free system we rely on showing a window with the computer vision process on the event toolbar. The cross on the nose is expanded and occupies the whole image to make it easy to visualize the tracking process.

- **R14.** The feedback must be in real time: the user should observe that the cursor's position reacts in the same manner as his head motion.

- **R15.** The system has to offer a visual feedback of the user's action. As all the interaction is carried out by vision techniques with no physical contact with any device, a visual feedback is offered at all moment in the events' toolbar to communicate with the user.

- **R16.** The user has to be always aware of the situation of the interface. The event selected has to be marked and if any error occurs the system has to show a message.

Usability recommendations with impact on design

These recommendations are those that build diverse functionalities into the software to enhance the interaction between the user and the system. These recommendations go further than the UI ones, as these ones imply a change in the core of the system, not only a change in the presentation of the interface. One of the important issues of an input system is to adapt its functionalities to the user like for example in the mouse case, one can set the speed or how fast will the double click be. In our hands-free interface, there is a configuration file for each user profile.

- **R17.** The interface should adapt to the user. We provide a configure file for the user's personal settings .

The settings in the file configuration are:

- Click time: how long is it needed to keep steady on a position for carrying out an event (in frames per second). This setting is needed as some users find it difficult to keep steady as they have got spasms or tremors.
- Range of click: the area around the active zone of the cursor where the events carried out are effective (in pixels).
- x jump and y jump: constants used in the mapping of the image point to the screen point. If the user's neck range is small, these parameters will allow him to reach the screen corners' with little motion. Higher values will mean that it is easier for the user to reach the corners but less precision. The size and the position of the items which the user will work with should be taken into consideration.
- Position of the event keyboard: north, south or east part of the screen.
- Initial mouse's event: event selected for when the interface is initiated.

The first prototype pretended to calibrate the system taking into account the motion range of the head's user and the physical screen size in order to calculate the x jump and y jump. Nevertheless, the first test with real users was not successful and therefore it was decided to include them in a profile configuration. Moreover, for several cerebral palsy users which just carried out action/reaction tasks they needed to have already selected an initial mouse event as they still didn't work with the event toolbar.

The profile selection window will only appear if more than one user works with the hands-free interface on the same computer. In the cerebral palsy centre only two computers were used, one for the day care centre and the other one for the school, so a selection of the profile was made. When working in a house, probably there will be only one user needing this input device, and therefore the interface will automatically read his profile. This will make the user gain independence and in no need of assistance, apart from someone switching on the computer, as the interface will execute when the operating system starts.

- **R18.** The profile selection window will only appear if configured. If only a user uses SINA in a computer, this window does not need to appear.

While observing the users working for twenty or thirty minutes in each session, they had spasms, fast head movements, distractions or several users' head tilted to one side as it was their normal head position or because they got tired and could not hold their head straight. This caused the mean point of all the tracked features to displace and move out of the nose region, that is, features didn't get lost, just displaced and therefore the tracking continued processing but moving the cursor was not so easy. We had to add to the Processing phase a step to recover and update the features used to track, see Fig. 3.10. Every time the user's face is looking up towards the webcam, we search for good features to track again on the nose region and update the set of features we are tracking, adding just a percentage of found features. The user does not participate actively in this phase, unless his normal head position is tilted, then he will notice that the cross is not on his nose and he will have to straighten up his head. Finally the user will just feel a subtle readjustment of the red cross on his nose. This process demands a high cost on resources but it improves greatly the operation with the hands-free interface for users with cerebral palsy.

- **R19.** The system should always track the features around the nose region. If features get displaced, whenever the user looks straight into the webcam, we will readjust the tracking features to centre them in the nose region.

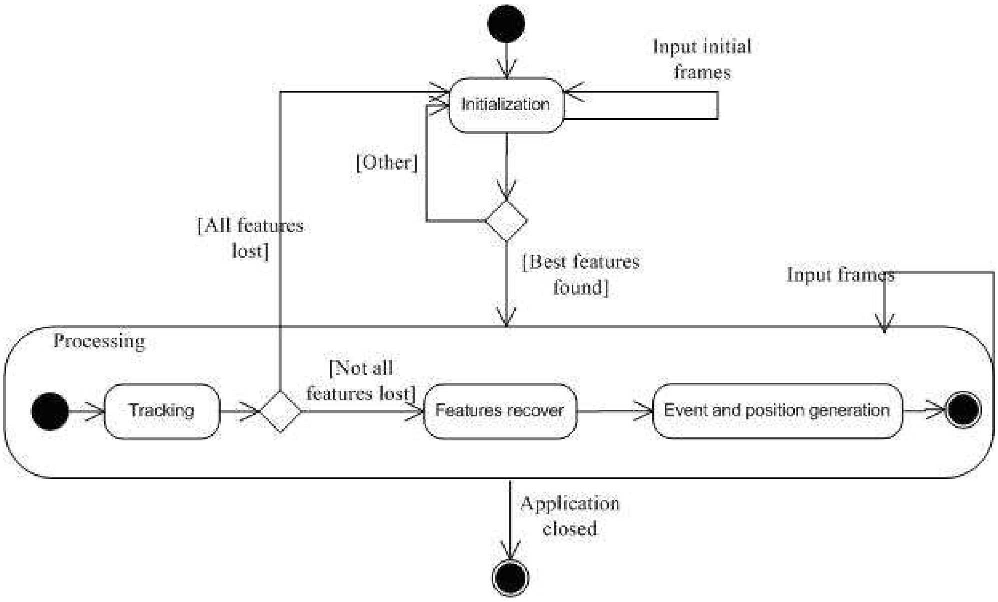


Figure 3.10: New UML-like diagram of the system. It includes a new module for recovering features.

3.4.5 SINA training

The pedagogical group that was involved in the project and that monitored the evolution of the users with the interface decided that for the them to master the system with accuracy and efficiency, they had to practice continuously. They started with different tasks such as viewing presentations with Microsoft Powerpoint or searching for images in internet, but then we designed together (pedagogical group, therapists and technical group) a set of games for speeding the learning process.

Three kinds of games were designed:

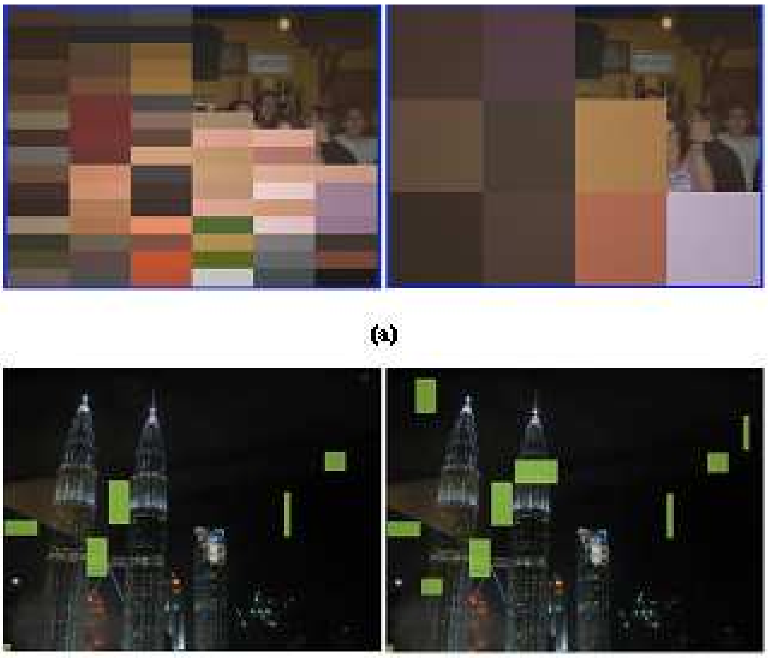
Group I: The first group of games is the action-reaction games. The users need to understand that their head motion means something to the computer, that is, an action of their head creates a reaction on the screen. It is very important that the computer shows a feedback in response to the participants' action [75], because humans can learn behavioural patterns implicating the coordination of action and perception [113]. Two games were developed with this purpose.

- Game I.a: An image is covered with colorful blocks and the user has to turn them in order to discover the image under them. The way of uncovering these blocks is passing over them with the cursor. It is very intuitive as while you move your head you see how they go disappearing. The difficulty of this game can be increased or reduced by changing the number of blocks that covers the image both in the X axis as the Y axis, see Fig. 3.11. The image can also be set by the therapist for motivating the user by putting an image of the family or something of interest for the user.

- Game I.b: Similar to the game before but the therapist chooses the number, the size and the position of the blocks. The image is not all covered by blocks, only where the therapist specifies, see Fig. 3.11. This allows the therapist to make the user direct the cursor to the desired zones, whereas, game I.a, most of the movements uncover blocks.

Group II: The second group of games is to practice vertical or horizontal movements, without taking into account other kinds of motion.

- Game II.a: it is a game to practice the vertical movement. Darts fly from the right side of the screen and a dartboard has to stop them. The dartboard only reacts to the vertical movement of the head's user. The game has been designed in a playable form, that is, with levels and lives. Difficulty can be increased by speeding the flying velocity of the darts, and the size of the darts and the dartboard can be reduced in order to make harder the activity, see Fig.



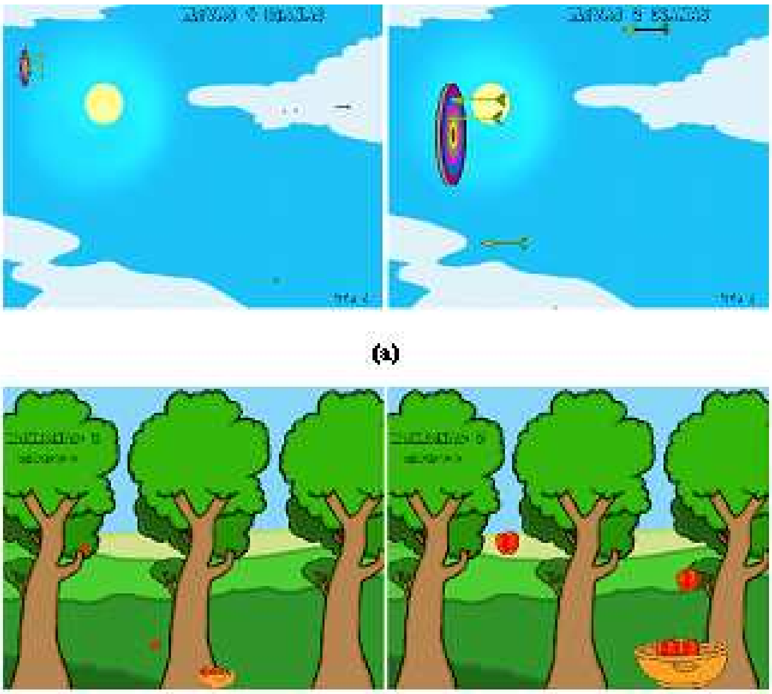
(a)

(b)

Figure 3.11: Action/Reaction games. Game Ia, Game Ib.

3.12. Moreover, when a target is not stopped a live is taken. This motivates the user to play more concentrated and with an objective.

- Game II.b: it's the same game as Game II.a, but instead of reacting to the vertical movements, it reacts to the horizontal ones. Apples fall from the sky and a basket that moves only horizontally has to retrieve them. Levels, lives and the increase of the difficulty is similar to Game II.a., see Fig. 3.12.



(b)

Figure 3.12: Motion games. Game IIa, Game IIb.

Group III: The third and last group is games to practice the events of the mouse. As it was mentioned before, the system works with wait-and-click. All the events, except the drag event, are simple to use, as you only need to select the event and whenever the user stops in a zone for several frames, it will be executed. The drag event works differently as it means: select the event, keep steady for the press-down button of the mouse in a zone, move, and keep steady again for operating the release of the button.

- Game III.a: this game is for positioning different objects by dragging them to any place in the scenery, see Fig. 3.13.
- Game III.b: this game is for working the other mouse's events. It is done with the left click event, but all the other events work in the same manner. It is an application that as well as working the events, works the head control. The therapist can decide where to put the targets, their position and their size, see Fig. 3.13. Then targets go appearing one by one when the user clicks over the last target, and consequently lines go joining the targets.

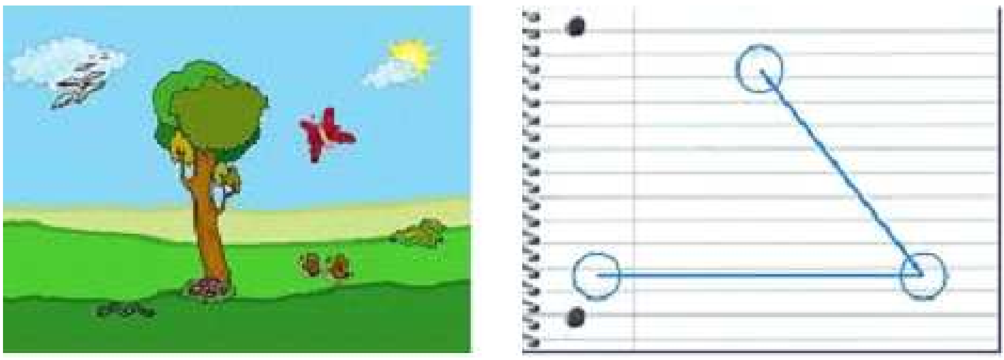


Figure 3.13: Events games. Game IIIa, Game IIIb.

Chapter 4

User performance and results

What users want is convenience and results.
Jef Raskin.

In this chapter we are going to explain the different tests that have been carried out with users with and without motor impairments. The first section corresponds to the tests and users' observation carried out in the developing process during the first phase of the project and which helped us to improve the design and development of the hands free interface. Then we will describe the evaluation tests of the final system corresponding to the second phase of SINA project. We have evaluated the interface on users with no disabilities in laboratory conditions and with cerebral palsy users in their usual context. Evaluation was supervised by the development group, by external evaluators and by the cerebral palsy users' therapists.

Most of the cerebral palsy users that participated in the project already used assistive tools, so they were potential users of the hands-free interface and ideal to evaluate it and offer their feedback. In Fig. 4.1 we can see different users working with SINA, as well as other used input devices. We have to highlight that cerebral palsy users not only count with physical limitations in the upper body limbs. Some of them present spasms, involuntary movements and different cognitive level, and therefore, evaluation has to be adapted to their capabilities.

In all the tests, the user placement is important for the application to work correctly. The user has to sit in a comfortable position without stretching his neck or forcing a strange pose. The webcam should be located in the most suitable place for the user: on the screen, on the table or using a support.

Figure 4.1: In the left column users are working with the hands-free interface. In the right column several other assistive tools which are also used: joystick held with the chin, mouse, head wand, switches and numerical keyboard.

4.1 Users performance in the first phase: the developing process

The following tests have helped us to improve the design while developing the system.

4.1.1 Laboratory evaluation

The first test was done in laboratory conditions with non-disabled users. This evaluation was intended to prove that the system tracked correctly the user and that the precision of the click was adequate to work.

The images for the performance evaluation were captured with two webcams: a Genius VideoCAM Express USB Internet Video Camera and a Logitech QuickCam Messenger [1]. The cameras are not assumed to be calibrated and they provide 320x240 images at a rate of 25 frames per second. The computer's configuration where the tests were carried out was a Pentium IV, 3.2 GHz, 1GB RAM. Although the system has been tested on less powerful machines without any noticeable loss of accuracy. The webcam was placed on the computer screen at the forehead height.

To evaluate the application's performance, the hands-free interface was tested by two different sets of non-disabled users: one set that had never experienced with the application whereas the other set had been previously trained with the interface.

A grid of 25 targets arranged in five rows was presented on a 17" computer screen with a resolution of 1024×768 and the users had one opportunity to click on every target; each target had a radius of 15 pixels, see Fig. 4.2. We stored the distance error between the cursor's position and the nearest target on the grid when the user clicked outside the target.

The first experiment was performed on a group of 13 people without any previous training. In this case, the results showed that a user with no preparation can place the cursor correctly on the desired position of the screen in most cases. Also, the distance error is related to the circle position on the screen, that is, it increases when the user tries to click near the screen boundaries. Specifically, 80.4% of the errors

[1] Any webcam that supports RGB24 and a resolution of 320×240 is suitable

occurs when the user tries to click in one of the four targets placed farthest from the screen centre, that is, on the targets near the screen corners.

The second experiment was performed on a group of 9 people that had previously used the system several times before. In this case, as summarized in Table 4.1, the errors and their distances decrease dramatically. With trained users, there is no relation between the screen positions and the accuracy of the system.

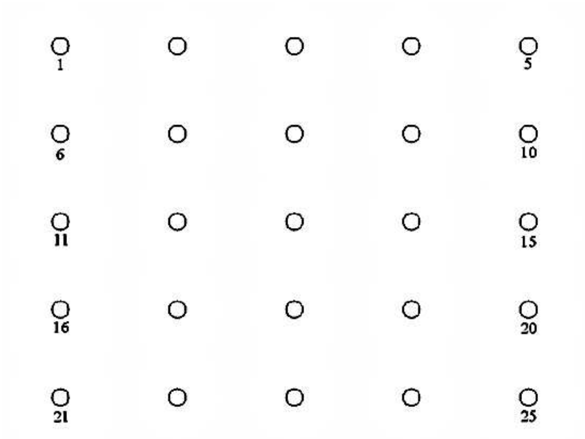


Figure 4.2: The point grid pattern used for the performance evaluation of the interface (the circle radius is 15 pixels).

Users Group	Clicks over targets	Distance error (mean)
New users	85.9%	5 pixels
Trained users	97.3%	2 pixels

Table 4.1: Results of the accuracy test for non-disabled users.

These tests showed the fullfilment of two objectives: first, that the hands-free interface is robust as the user can rotate and move his head in a quite wide range (facing the screen) without loosing the features being tracked and second, that users can perform with a high percentage of success the tasks to carry out.

4.1.2 External evaluation

A second test was done by external evaluators from the Automatic Control Department at the Technical University of Catalonia with users with no motor disabilities and in laboratory conditions. This test was carried out by a group totally independent from the SINA project. They applied the GEDIS guide [85] to validate the hands-free interface in order to improve the user interface design. The design recommendations were described in the previous chapter. Moreover, they tested the hands-free interface for working with a domotic house system.

Tests were evaluated by eight non-disabled users using a Quickcam Logitech 4000 Pro webcam and a screen resolution of 800 × 600.

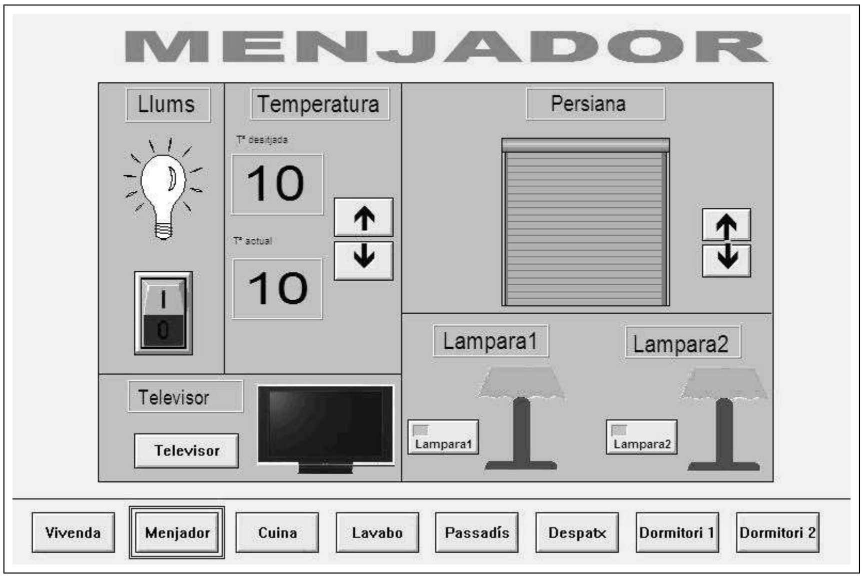


Figure 4.3: Domotic scenario.

The test consisted in performing a set of predefined tasks on the domotic interface and specifically on the "sitting room" window, see Fig. 4.3. This window is divided in five blocks: lights, temperature, shades, television and lamps. Users had to execute eleven tasks:

- Six control actions: activate and deactivate elements.

- Three navigation actions among the different windows of the domotic interface.
- Two selection actions of the temperature and of the television channel.

Before starting the test, users received a brief explanation on how the hands-free interface worked and which tasks they had to perform. Then they moved their head in order to try the hands-free interface and to observe its behaviour. After completing the eleven tasks, they answered a satisfaction questionnaire. This satisfaction questionnaire consisted in six questions measured in a 4-point interval Likert [59] scale and in two open questions for assessing the user on the domotic interface and the easiness to work with the hands-free interface.

The effectiveness results were that all users could finish successfully the eleven tasks. The average timing for carrying out the tasks was of 96 seconds, with a maximum timing of 103 seconds and a minimum of 82 seconds. Regarding the questions related to the hands-free interface in the satisfaction questionnaire, six of eight users considered the use of SINA in a 4-point Likert scale *satisfactory* or *very satisfactory*, although they recommended to improve the smoothing. Two users found the hands free interface *not too satisfactory* [2], although they indicated that the task should also be revised and modified in order to be more suitable to SINA [84].

The conclusion of this test is to reaffirm the correct use of the hands-free interface to successfully carry out tasks. It is important to remark that these tests were not controlled by the development group and therefore, it is highlighted the interface's ease-of-use and the documentation's quality for understanding how the hands-free interface worked and was installed.

4.1.3 The evaluation of ASPACE's therapists

ASPACE is a cerebral palsy centre divided in a school (user's age is up to 18 years old) and a day care centre. As part of the educational program, the users have computer

[2] *Not satisfactory* was the fourth answer

sessions and they use access devices suitable to their capabilities and cognitive level. The sessions are controlled by a therapist who decides the user's tasks.

The users' selection was done by the centre's therapists and they were chosen taking into account the next criteria:

- A need of an alternative device for accessing the computer, giving priority to those users whose access system was not too effective.
- The possibility of continuing with their education and training program. The second reason for choosing the users was that once the access was solved, the users had to be able to continue their educational program with the computer.
- Previous experience with computers. Although the use of the hands-free interface does not need previous experience, the therapists wanted the users to focus on the tasks and not on the use of the computer.
- Sufficient cognitive level for understanding the interface and the instructions of the therapists.
- Physical conditions: a minimum head control and sight control.

Six persons, four children from the school and two adults from the day care centre were selected to participate in the project. In Table 4.2 the user's profile is defined. Users' ages ranged from 5 to 42 years and there were 2 women and 4 men. The sessions were carried out during five months, 20 minutes for the children and 30 minutes for the adults. Each user performed from 20 to 26 sessions. The validation of the hands-free interface was supported and controlled by the therapists and the pedagogical group. All sessions were observed by a therapist and an assistant that was in charge of monitoring the evolution of the users by filling a spreadsheet, see Annexe C.

Later these spreadsheets were analyzed in order to explain results. Users carried out their own tasks, that is, they continued working with their personal educational activities, but incorporating new tasks that before they could not achieve due to their input device.

Id	G	Age	Diagnosis	Previous access method
U1	M	5	Child's CP spastic quadriplegia with left predominance.	Switch scanning mouse.
U2	M	12	Multi-handicapped case of CP. Child's CP, quadriplegia, spastic-athetoid with major affectation in inferior limbs by spasticity and in superior limbs by athetoid. Frequently he suffers from breathing and digestive problems as well as epileptic seizures.	Switch scanning mouse. He has tried different joysticks but with no acceptable results.
U3	F	14	Glutaric academia type 1	Head pointer, joystick handled by the chin and mouse emulator.
U4	F	42	Progressive spinocerebellar neurodegenerative disease.	Numerical mouse or standard mouse.
U5	M	30	Spastic quadriparetic cerebral palsy with bipolar affective. disorder	Numerical keyboard with a keyguard and he typed using a pointer or a finger.
U6	M	16	Muscular dystrophy of Duchenne with hyperactivity diagnosis.	Standard keyboard and mouse.

Table 4.2: CP users' profile in the designing and development phase.

Next, we will explain one by one the observation done by the therapist of each user. We have to take into account that the system was continuously modified during the designing and developing phase.

- User 1, a five years old boy, accessed the computer by means of switches before trying the hands-free interface. The goals proposed for him were to improve his head control and to increase his autonomy as well as his interaction with the environment. He had a high level of motivation and during his sessions with the interface he was able to control the mouse's position and maintain the posture steady for executing mouse's events. It is important to highlight that the user maintained the head totally straight during the sessions, but a physical deterioration made him abandon the sessions and therefore he was removed from the project, this means that spreadsheets were not filled in his sessions. At the end of the first phase of SINA project he was still using the system as an access tool although he was not included in the research project and his tasks with the computer were action-reaction applications. The therapists opinion was that this interface could be used for him for reinforcement tasks and for working his head control.

- User 2, a twelve year old boy, accessed the computer by means of switches before the hands-free interface. He had tried different joysticks but with no acceptable results. The goals to achieve were to develop his spatial organization, improve his accessibility and his interaction with the computer and dissociate his head movements. At first, he could not follow the instructions and his head motion was abrupt and without coordination. He was not able to control the mouse's cursor and he needed verbal and physical assistance from the therapist for carrying out the movements. He couldn't concentrate by himself and he was continuously loosing the focus of attention, and therefore loosing the tracking point of the nose. For his training, very simple exercises in Microsoft Paint and Powerpoint were used. During the sessions, although it was difficult for him the use of the interface, his motivation was always high along the twenty minutes sessions. At the end of the evaluation of the first prototype, he was able to move the cursor to the desired position, and although sometimes he used the trial and error technique, he always reached the target. He was capable of producing smooth and slow head movements and his motion was more coordinated and constant. Moreover, he was able to focus and concentrate in the tasks and he was working with more complicated applications. The interface allowed the user to explore orientation in a direct way and he was starting to work autonomously with simple programs.

- User 3, a fourteen years old girl, used a head pointer for accessing the computer as she had total control of her head. While she was learning the hands-free interface, she also started working with a joystick handled with the chin, as they wanted to try different devices for selecting the best one for her for the future.

The goals were to improve her access and interaction with the computer, achieve a more functional communication and correct her general working posture, as it was very tiring to work with the head pointer. In her first sessions with the interface, she worked with the neck flexed and making a great motor effort. She frequently lost the tracking point due to her involuntary movements or because she paid attention to other stimulus. The trajectory of the cursor was discontinuous and not coordinated and she could not maintain the cursor steady for carrying out an event. During the sessions she participated dynamically in the tasks' selection and her training was done with memory games and educational applications. At the end of the evaluation of the first prototype, she controlled her head totally and her posture was better and not so stressed as before or when using the joystick. She was more relaxed and she hardly presented involuntary movements when she was working with the interface. She was able to move the cursor in a controlled way and to follow trajectories as well as keeping the cursor steady in a position in order to carry out an event. Moreover she was starting to use the graphical keyboard for writing. The therapists and the user stated that this interface offered her a faster method to access the computer and up to that moment it had been the best device for her.

- User 4, a forty-two years old woman, accessed the computer via the numerical mouse and sometimes with the standard mouse but presenting many difficulties. The goal to achieve was the improvement of her accessibility. Initially she used to get tired physically and psychologically. She was not able to move the cursor to a desired position because of her lack of head movement's coordination. She was not able to keep steady in a position due to her tremors and at first it was difficult to personalize her settings. During the sessions she started training orientation issues and to keep steady the cursor with Microsoft Paint. At the end of the evaluation of the first prototype in the first phase of SINA project, she was working cognitive aspects with educational applications and she could work with the interface in a more relaxed and successful way. She did not get tired and she was starting to use the system in the computers' room with no need of a therapist.

- User 5, a thirty years old man, accessed the computer by means of the numerical keyboard with a keyguard and he typed using a hand pointer or a finger. The goals to achieve were the improvement of his head control and offer him a better access and interaction with the computer. In the first sessions, he tried to control the cursor using the gaze, and the initial detection of his face was difficult due to his normal tilted head position. During the sessions, the tracking point used to get lost frequently due to his lack of head control and he was almost taken off the project as it was not too efficient for him. But together with the center's physiotherapist, they decided to use the hands free interface for reinforcing his head control and motion by using Microsoft Paint and Powerpoint templates for exercising his neck. At the end of the evaluation of the first prototype, he was working cognitive aspects with educational applications using only the click event; however, he could not yet click on the graphical event toolbar. The interface allowed him to train his head control and to interact in a more functional way than other devices.
- User 6, a sixteen years old boy, was the 'control user' as he could interact with the computer with the standard mouse and keyboard. The goals for him were to experiment with alternative access devices as it was necessary to introduce him in assistive technologies due to his most probably future physical deterioration. In his first sessions he showed a very good control of the cursor's motion although it was difficult for him to stay steady for selecting an event of the toolbar. During the sessions, his training was done with car games and by searching images in internet for creating Microsoft Powerpoint presentations. At the end of the evaluation of the first prototype, he was able to use it in a independent way, he used all the events in the graphical event toolbar and he was capable of writing with the virtual keyboard. Moreover the interface had improved his body posture.

The therapists' conclusion is that all users improved their operation with the hands-free interface. Obviously their experience working with it helped in the process, but the modifications that the system suffered due to the feedback also influenced. The profile settings, the automatic recover of displaced features when the user works and centres the point again on the nose, the hiding of the window with the user's face or the feedback given at all moment have made the system more usable and therefore suitable for these kind of motor disabled users. Users were able to carry out successfully the tasks presented by the therapists and they understood how did the hands-free interface work. Moreover, working with the hands-free interface allowed a better body posture and a better access to the computer for most users. Several users worked with the interface rehabilitation or spatial organization issues.

Satisfaction and fatigue evaluation

We extracted more results of the spreadsheets' analysis. These spreadsheets correspond to the users' first twenty sessions and we paid special attention to the satisfaction and the fatigue information. Therapists observed that the user's mental and physical state for a particular day influenced greatly on the task performance, therefore the importance of controlling an evolution to study if fatigue decreases and to know the satisfaction of the users. Fatigue and satisfaction were classified in low(1), medium(2) and high(3), see Table 4.3.

From these data a positive point for the system is that although for several users is tiring, satisfaction is encouraging. The therapists experience is that most of the pointing devices for accessing the computer demand a physical effort from the user and users get tired.

Effectiveness and efficiency evaluation

Comparisons among devices for controlling effectiveness and efficiency measurements were also carried out. Each user performed a different task and duration was measured.

These efficiency tests with cerebral palsy users differ greatly among users, as the tasks' duration depends on the motivation or the physical and behavioural state of

Id	Fatigue	Mean 20 sessions	Satisfaction	Mean 20 sessions
U1	*			
U2	Variable. It fluctuates between Low and High	1.71	High	2.92
U3	Low	1.13	High	2.86
U4	At first is Medium but then it stabilizes at Low	1.35	Medium-High	2.32
U5	Variable. It fluctuates between Low and High	2.26	Medium	1.94
U6	In some sessions High but generally Low	1.56	High	3

* U1 uses the interface but he is not controlled by the spreadsheets

Table 4.3: Fatigue and satisfaction results after 20 sessions. They are classified in 1: low, 2: medium and 3: high.

the user on a particular day. What we consider more important working with cerebral palsy users is the effectiveness measurement, that is, if they could finish successfully the task. The tasks used for comparisons are next explained and a summary table with the timings of these tasks can be seen in Table 4.4. These tasks correspond with the educational program that these users follow.

The task of User 2 was to visualize a presentation done with Microsoft Powerpoint. For changing the slide he had to click over an image of 7.5 cm high and 10 cm wide and it was never put in the same area of the screen. The user needed 3 minutes 14 seconds with SINA and with the switch scanning mouse (with two switches) he did it in 2 minutes 26 seconds. Scanning systems together with switches have not much sense to compare as they are not a pointing device and moreover, they need the assistance of someone for scanning the screen. But what it is important is to demonstrate that the user can successfully carry out the task with SINA.

User 3 had to write with and without the virtual keyboard her name: “MARIA” The keyboard was 28 cm wide and 15 high and each letter was 2.5 $\times$ 2.5 cm. She did the test with the hands-free interface, a joystick held with the chin controlling the click with a button, the same device without controlling the click, that is, using a wait-and-click method, and finally using a head wand together with the physical keyboard plus a keyguard. The best time was with this last device in 10 seconds, the hands-free interface needed 43 seconds and the task with the joystick controlling the click was done in 2 minutes 49 seconds and without controlling the click she was not able to finish successfully as she wrote "ASSFHMZAAARIA".

Another task for User 3 was a web game, where the user had to position the cursor over several insects in order to move them over a path. The paths were zig-zags and there were 5 insects. The duration to finish successfully with SINA was 3 minutes 8 seconds and with the joystick handled with the chin, she needed 6 minutes 40 seconds. For User 3, SINA was up to that moment, the best input device for her, and still nowadays it is the access system she uses for interacting with the computer at school and at home.

User 4's activity was to relate images with words in English. She tried with 12 cards, 8.5×6 cm and with 18 cards 4×8 cm. In this case she worked with the hands-free interface and with the standard mouse. She obtained better results with the standard mouse, 3 minutes 29 seconds for 12 cards versus 5 minutes 45 seconds with SINA and for 18 cards she needed 6 minutes 12 seconds with the standard mouse against 9 minutes 52 seconds with our system. Again effectiveness was correct for both systems. The standard mouse efficiency is better for this user, although, therapists say that this user in particular works with a better posture when using the hands-free interface than using the standard mouse.

The task for User 5 was to carry out a game of Memory for educational purposes. There were 16 cards, 8 pairs, and the user had to discover where the pairs were. Every card was 6×6 cm. In this occasion, SINA was more efficient than the numerical mouse. With the numerical keyboard acting as a pointing device, after making 1 pair of 8 in 6 minutes 9 seconds, he was exhausted and he abandoned the tasks. Instead, with SINA he could finish the task successfully in 4 minutes 40 seconds.

User 6's activity was to click over the Internet Explorer icon, write Google's web (www.google.com) in the address bar, write COCHES ('cars' in Spanish) in the search textbox and click on the Search button. This user was the 'control user', as at that time he could use the standard mouse and the keyboard efficiently and with effectiveness. He could control totally his head and therefore, although slower than the combination of the standard devices, he could also finish the task with SINA and a virtual keyboard. Obviously, he was really fast with the standard input devices as he needed only 16 seconds for carrying out the complete task. With SINA, he used 1 minute 14 seconds.

Id	Tasks	SINA	Previous system
U2	Power-point	3m14s	Switch scanning mouse (two switches): 2m26s
U3	Insects	3m08s	Joystick handled with the chin: 6m40s
	Writing	43s	Joystick handled with the chin+virtual keyboard: (a) Without controlling the click: 1m49s. She wrote ASSFHMZAAARIA (b) Controlling the click: 2m49s With the head pointer and real keyboard+keyguard: 10s
U4	12 cards	5m45s	Standard mouse: 3m29s
	18 cards	9m52s	Standard mouse: 6m12s
U5	Memory	4m40s	With numerical keyboard: after making 1 pair of 8: 6m09s Afterwards, he was tired so the task was abandoned
U6	Search image	1m14s	Standard mouse and keyboard: 16s

Table 4.4: Quantitative results for comparison tests with different devices.

We can conclude that when tasks involve writing all the users that could use the keyboard were faster with the keyboard than with any other device using the virtual keyboard. We have to take into consideration that the hands-free interface needs in a default configuration approximately one second to perform any event. Scanning systems together with switches have not much sense to compare as they are not a pointing device and moreover, they need the assistance of someone for scanning the screen. Therefore, although they may be more comfortable, they don't allow the user a complete interaction with the computer. These tests can help in selecting the different assistive devices for the users together with the satisfaction and fatigue data that are two very important issues in HCI contexts. The hands-free interface demonstrated that all the users perform their tasks with effectiveness and satisfaction.

4.2 Usability evaluation of the final system

Once the system was approved to be usable and useful by the users, the developers and the evaluators due to its effectiveness, efficiency and the users' satisfaction carrying out tasks, new tests of usability were done in order to present formality in the results and more objective tests. This evaluation was carried out in the second phase of SINA project.

Literature review demonstrates that there is no formal test for evaluating computer vision interfaces replacing the mouse. Interface developers design their own evaluation systems and they are rarely compared among them.

Researchers compare their performance with other devices. They usually compare a task using different access devices and taking into account the duration. Palleja et al [79] carry out a performance comparison among their hands-free device, a conventional mouse, a digital joystick and a touchpad. Their validation test is done on users with no disabilities. A target appears in a random position waiting for the user to click, and then a new target appears in another random position. The maximum error corresponds to the touchpad and the minimum to the standard mouse; their system and the joystick have intermediate values although the slowest system is the hands-free mouse.

Perini et al [81] tested their system on disabled users and compared their interface with scanning systems with switches. The task was to type a sentence of 25 characters with their virtual keyboard (using prediction and no prediction). They present very good results, although, scanning systems for writing are already known to be very slow, therefore another test with no writing involved would have been interesting to compare.

The Camera Mouse of Betke et al [10] was tested on 20 users with no disabilities playing a game of aliens and compared with the standard mouse. The users had to point the alien without any mouse event. The mouse came out to be faster than their system by a factor of about 1.6. A second experiment was to type with a virtual keyboard, that is, it needed clicking. Results came to be the same as the pointing device if we take out the click time needed to activate a click event. People with disabilities, 10 with cerebral palsy and 2 with a traumatic brain injury caused by traffic accidents, also tried the system but each of them did different tasks. Some typed, others played the aliens game and others surfed the internet and therefore it is stated mostly comments, qualitative information and if the users continued using the Camera mouse.

Mauri et al [66] compare the computer experience of cerebral palsy users with their system and their previous systems using a qualitative evaluation. They used a very simple scale: no improvement, slight improvement and great improvement with the new system. The tasks to carry out were basic computer interaction, educational software and common computer desktop applications such as drawing or writing. The work does not present any quantitative results.

Hannuksela et al [42] did not try the system over disabled users and they neither presented an exhaustive evaluation, they draw the trajectory of the mouse and say that the movement seems to be roughly correct. About the users participating in the evaluation of El-Afifi et al's [27] system nothing is said. They have tried the system with a drawing program and using it with the Snake game that involves simple direction movements but with no evidence of the results.

Gorodnichy et al [38] carries out several tests on users whose capabilities are not presented: a robustness test making the user move in all possible rotations while looking at the computer. A precision test making the user draw words, vertical and horizontal lines and a circle. More than fifty non-disabled persons played an aim-n-shoot game, Bubble Frenzy, and they agreed that it was more fun using the nose. They say that several users got less tired playing this game with their system than with the standard mouse. Finally, navigation tasks within a virtual 3D world or the traditional Pong game also was tested.

Morris and Chauhan [71] have tested metrics for the interface on "several naïve users" more than analyzing the user carrying out a task. The interface was tested without any other application running. They studied the maximum throughput rate for the webcams with several frame sizes, accuracy with which the nostrils were located, the robustness considering extreme head positions or lighting variations and the accuracy of the cursor positioning (1cm target on a 19” monitor).

Kjeldsen’s HeadTracking Pointer (HTP) [56] is tested on users with cerebral palsy and spinal cord injuries and with users without disabilities. It has also been compared with the CameraMouse. The users had to use both systems for typing with a virtual keyboard sentences with 12 to 15 characters and time was measured. Their principal problems were the consideration of assuming the head motion as symmetrical and relatively smooth and the appearance of erratic head motions. Comparing both systems, users’ performance was better with HTP than with CameraMouse. Moreover, users considered that the pointer motion was less erratic, the pointer was easier to keep still and the overall quality of the HTP pointer motion was better, although they needed some time to get used to control the pointer accurately.

As seen, evaluators of vision-based interfaces with disabled people do not use common tests.

4.2.1 Usability evaluation using ISO 9241-9 and MacKenzie’s parameters

ISO 9241-9 recommends to test comparatively novel input devices with commercially available ones as they should generally be accepted by the user population. In the case of assistive technology, and in particular vision-based interfaces using similar techniques as the one being presented in this thesis, there are commercial systems, but none is really standard nor popular. Therefore, SINA will be compared to Crea Ratón Facial [66], as it is a similar system being used in centers with cerebral palsy users. It was a commercial product which costed 300 euros, although there is a free open source version now. For the comparison we used the purchased system.

Users with no disabilities evaluated both systems with the ISO 9241-9 Multidirectional tapping task which uses throughput(bits/s) as measurement. To study the throughput we used FittsStudy. FittsStudy is an integrated tool for conducting, analyzing, and visualizing pointing performance studies provided by J. Wobbrock from the University of Washington. The software is being used to test the Vocal

Joystick [43], the Angle Mouse [116] and a group of industrial collaborators are using it to evaluate the performance of multiple eye-based pointing techniques.

Up to our knowledge, only De Silva et al [103] have tested their VBI with the multi-directional tapping test. They evaluated it with eight novel users with no disabilities. They presented the multi-directional tapping task of the ISO 9241-9 with a 240 pixel diameter circle at the centre of a 640×480 pixel resolution monitor with seventeen targets (diameter: 21 pixels) spaced equally around the circle's perimeter. Users pressed the space bar to indicate reaching a target. Each user repeated 20 times the task alternating between their hands-free system and the standard mouse. They obtained an average throughput of 2.0 bits/sec with the VBI and 4.7 bits/sec with the mouse for the last five trial.

Our tests were ran full-screen on a 13.3” monitor and the screen resolution was 1280×800 pixels. Each user performed two tests, one with SINA and one with Crea Ratón facial. As no warming up was allowed, the configuration was the one given by default for both systems, although when users started the test, they moved the cursor to the corners in order to see that they could scan the whole screen. If they had difficulties reaching the corners, then the settings were changed (x and y jump in SINA, velocity horizontal and vertical in Crea Ratón facial) The *Time click* was one second for both systems.

Users

Ten volunteers, five women and five men with ages between 27 and 41, participated in the experiment of using SINA and Crea Ratón Facial in the same task. Users were totally novel in the use of both interfaces and similar devices. Each user was given a brief introduction to how the systems worked and then they tested it to ensure they could reach all corners comfortably. Five users started with SINA and five with Crea.

Test

The multi-directional tapping task was then explained, that is, a circle with 17 targets equally spaced around the circle's circumference. The targets are arranged so that the movements are nearly equal to the diameter of the circle. The test session starts after the user points to the topmost target and ends when the sequence is completed. The active target is blue colour for indicating it the user. The test was conducted with different difficulties, varying the size of the circle and the targets.

- Trials per condition: 17
- Treat as practice: 3
- Circle amplitudes (A): 256, 384, 512
- Target width (W): 64, 96, 128
- Fitts' index of difficulty: from 1,585 to 3,1699
- Total trials: 153

Each test had 9 blocks, that is, the 9 combinations of $(A) \times (W)$ with 17 trials or targets each, the first three of which were practice unbeknownst to the participant, and the order of the blocks was random. Breaks were allowed between blocks and each user was about 20 to 25 minutes in completing both tests. The total number of trials for all users was: 17 trials x 3 amplitude x 3 width x 2 devices x 10 users = 3060.

Effectiveness and efficiency

As our main criterion in the comparison of the devices we use the throughput as defined in the ISO-9241-9. This number incorporates both speed and accuracy in a single measure. We also show the movement time that is the average movement time in miliseconds needed to click on a target and the percentage of errors. We have to take into account that these hands-free interfaces work with wait-and-click, so therefore this increases the movement time. In this experiment, results show that SINA's average throughput is slightly better than Crea Ratón facial, the percentage of errors is lower and the movement time is slightly higher but differences are not too significant. Table 4.5 show the average values and in Annexe A individual information on the tests is found.

Device	Average MT(ms)	Error(%)	Tp(bits/secs)
SINA	2846.1	0.554	0.88584
CREA	2643.9	0.713	0.84968

Table 4.5: Average for Movement time (MT), Error rate (%), Fitts' throughput(TP). For all measures except TP, lower is better.

Trajectories followed by every user have been saved to analyze them and to extract MacKenzie's parameters [62].

We recall briefly MacKenzie's parameters that were described in Chapter 2:

- Target re-entry (TRE): a count on how often the pointer enters the target region, leaves and then re-enters the target region. The ideal is 1.

- Task axis crossings (TAC): a count of how often the task axis from the start point to the target center is crossed. The ideal TAC is 0.

- Movement direction changes (MDC): a count of how often the path changes direction parallel to the task axis. The ideal MDC is 0.

- Orthogonal direction changes (ODC): a count of how often the path changes direction perpendicular to the task axis. The ideal ODC is 0.

- Movement variability (MV): a continuous measure indicating the extent to which the path lies on a straight line parallel to the task axis. The ideal MV is 0.

- Movement error (ME): a continuous measure of how much the path deviates from the task axis. The ideal ME is 0.

- Movement offset (MO): a continuous signed measure of how much the path deviates from the task axis, where equal deviations to either side of the axis cancel. The ideal MO is 0.

In table 4.6 we can see the averages of the ten users for these parameters.

In this experiment, three parameters are lower for most of the users using SINA: TRE, ME and MV. Technical information about Crea Ratón facial is not detailed but it seems they use a smoothing filter and acceleration [3], this would explain the higher value of TRE, that is, the smoothing filter makes the cursor's movement follow a tendency in a particular direction and the acceleration increases the movement range with faster movements. With Crea Ratón facial many times the cursor passes over the target and then the user has to turn direction.

Device	TRE	TAC	MDC	ODC	MV	ME	MO
Sina	1.10	1.97	5.19	1.74	12.26	13.09	-1.09
Crea	1.30	1.80	4.64	2.26	16.21	17.03	-1.99

Table 4.6: Mean values for MacKenzies path studies. The ideal for TRE is 1. The ideal for the other measurements is 0.

In this experiment, users using Crea Ratón facial had to control more their head movement in order to control better the cursor's movement. In the case of non-disabled users, this is not a problem once you get used, but our cerebral palsy users don't have that fine head control and they present more erratic movements.

Several path traces can be seen in Tables 4.7, 4.8 and 4.9. As it is observed, Crea Ratón facial movement is smoother and for non-disabled users that are used to the movement of the standard mouse it is a fact that they like. Although SINA's path don't go out from the circle region as often as Crea Ratón facial, specially when targets' width are smaller as its movement is easier to control.

Approximately, most of the data have similar values, but the major differences in values correspond to SINA's MV and ME, that is, the "wiggliness" of the line is lower and less deviated from the perfect path.

[3] In the default configuration, the smoothing is set to 3 and the acceleration is set to two.

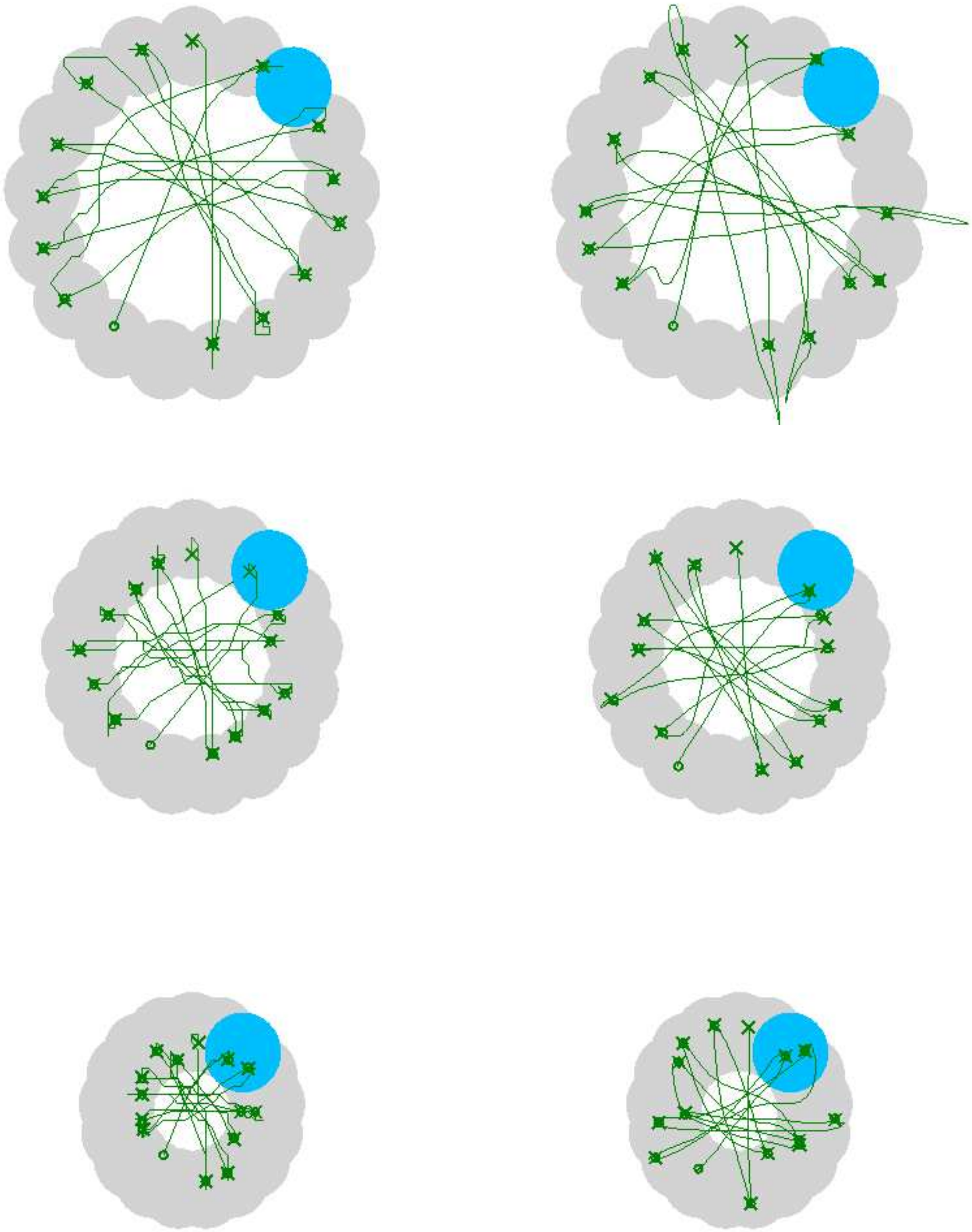


Table 4.7: Path traces for Sina (left) and Crea (right) $(512, 384, 256 \times 128)$ for Users Us4, Us3 and Us10.

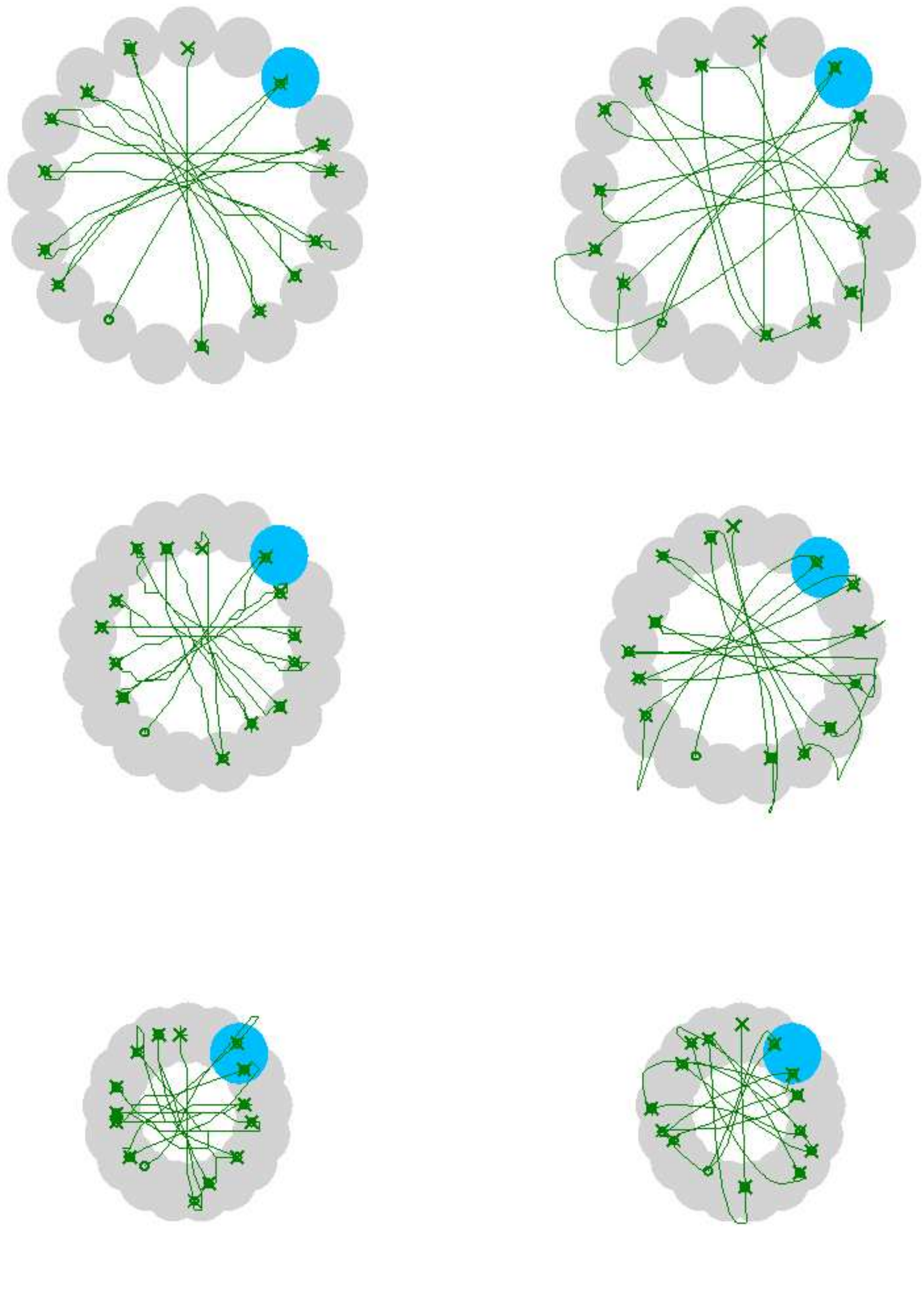


Table 4.8: Path traces for Sina (left) and Crea (right)$(512, 384, 256 \times 96)$ for Users Us2, Us6 and Us9.

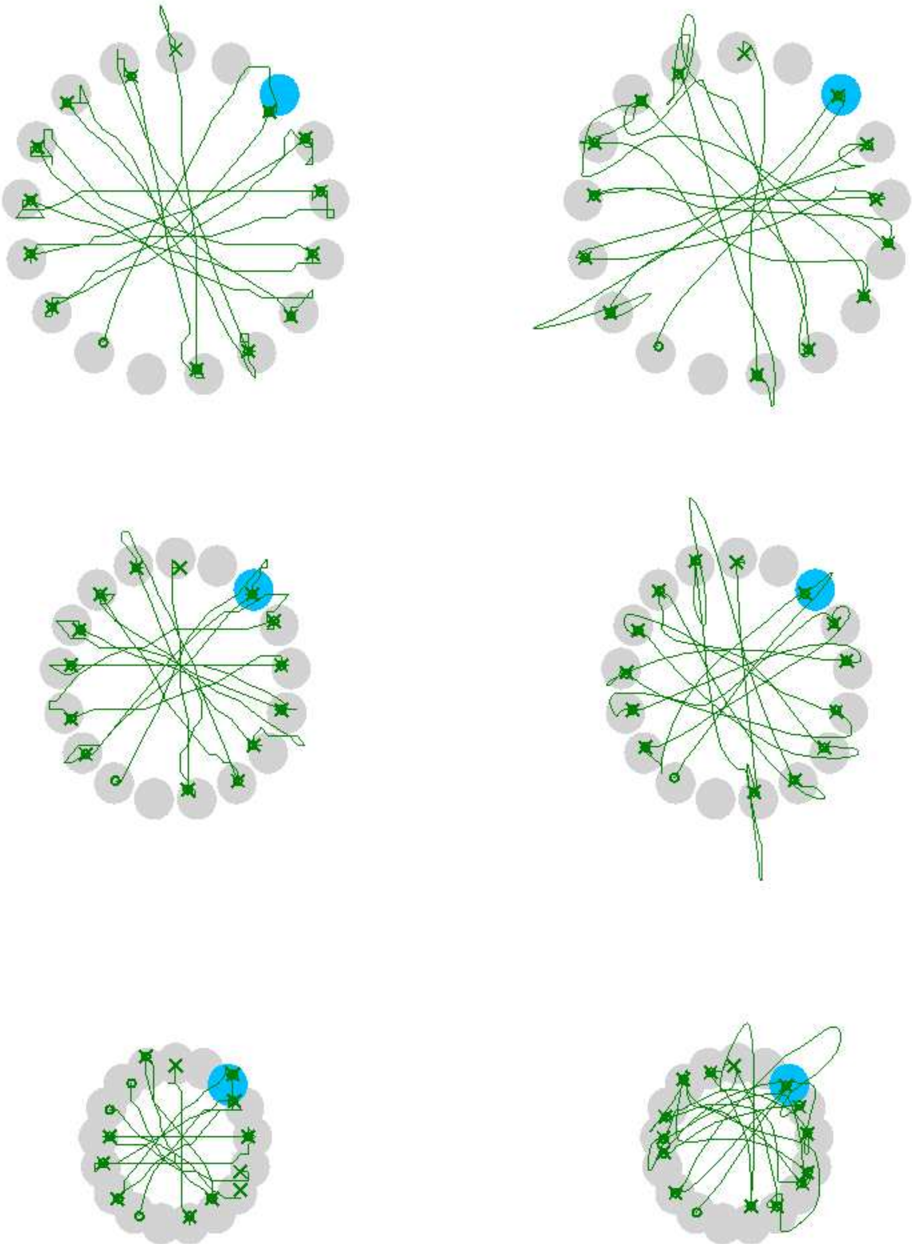


Table 4.9: Path traces for Sina (left) and Crea (right)$(512, 384, 256 \times 64)$ for Users Us5, Us8 and Us1.

We asked the users if it was difficult to use the interface and if they got tired using it performing the task [4] . Eight users found both interfaces easy to use and two of them a little bit difficult. All users coincide in their answers for both interfaces. The test is stressing as users have to do it as fast and accurate as possible. All of them found the task a little tiring with both systems, although none of them rested between blocks.

Several users mentioned that they had to move more their body with one interface, but then others said the opposite. Users commented that the feedback on what was happening was very important. In several occasions when the interface was not tracking correctly, with SINA they saw it immediately and they just looked straight into the camera for recovering the features. In the case of Crea Ratón facial they saw that the cursor was not responding correctly and they had to mark again where the face in the image was. The impact of this issue when working with cerebral palsy users has been very important and has improved totally their performance with the hands-free interface.

Instead, the event execution feedback was more intuitive for non-disabled users with Crea Ratón, as a circle starts drawing itself round the cursor and when it finishes drawing then the event is executed. Our experience with cerebral palsy users with an ocular tracking system with infrared light that performs this functionality is that they get distracted by the drawing of the circle, but maybe experience can overcome this fact and it can help them in the future.

Crea Ratón facial seems to work using skin colour, so for example, when a person passed behind the user doing the test, the cursor reacted to that movement. Moreover, when similar skin colours are present in the image, their automatic face detection may not be suitable.

When SINA starts working as a pointing device or whenever the system restarts, the cursor positions in the screen's centre. Crea Ratón facial starts controlling the mouse from the current cursor position. So the user's face may be centred in the image, but the cursor may not be centred in the screen.

[4] Questions 2 and 4 of the satisfaction questionnaire in Annexe D.

4.2.2 Usability evaluation with disabled users

Once achieved the final system, we wanted to formalize the results with the cerebral palsy users. We have designed four tests and a satisfaction questionnaire in order to measure effectiveness, efficiency and satisfaction as the ISO9241-11 recommends. When evaluating the usability with our CP users it is important to take into account the difficulties that we approach. First of all, each user works with different activities and tasks corresponding to their age, cognitive level, physical state and objectives. It is complicated to be able to compare the effectiveness and efficiency among users doing a task included in their educational program.

Their characteristics such as their cognitive level or the lack of spatial orientation will not allow us to present them the same usability tests as the ones done with non disabled users, that is, the ISO 9241-9 multi-directional tapping test that uses Fitts Law. Donker and Reitsma [24] and Hourcade et al [47] already commented that a special attention had to be paid when working with kids because they have lower movement efficiency. They present relatively limited motor skills and eye-hand coordination. This applies to our cerebral palsy users as they have motor impairments and several present low head-eye-coordination.

A set of general tasks were tested on all users and the information gathered together from these users was very useful as they are a users' group whose characteristics are suitable for the hands-free interface use.

It is important to highlight again that several users depend greatly on the mood and physical state on a particular day. In our case, it was common to obtain uneven efficiency results for the same task on the same day or on different days. Some days we were able to carry out up to 9 tests but then others only 3 were done due to motivation or other reasons. It is very difficult to control all these issues.

Users

In this evaluation phase we have five cerebral palsy users. Their profiles are detailed in table 4.10. Several users participated during the design and development process in the first phase of SINA project and others have been incorporated once the final system has been implemented. Users were selected in this case because the input system which they were working with was not totally efficient. This can be due the user's posture when working with the access device, the cost of the system, the involuntary movements that the user presents that can make him throw or displace the device if he has contact with it or other reasons. Moreover, the therapists working in the first phase of SINA project observed the possibility of using SINA for rehabilitation purposes and for working the spatial orientation. Therefore, some users have been included for working these aspects.

<table>
<tr><td>Id</td><td>G</td><td>Age</td><td>Diagnosis</td><td>Previous access method</td></tr>
<tr><td>U1</td><td>M</td><td>6</td><td>Child's CP spastic quadriplegia with left predominance</td><td>Switch scanning mouse</td></tr>
<tr><td>U2</td><td>M</td><td>13</td><td>Multi-handicapped case of CP. Child's CP, quadriplegia, spastic-athetoid with major affectation in inferior limbs by spasticity and in superior limbs by athetoid. Frequently he suffers from breathing and digestive problems as well as epileptic seizures</td><td>Joystick</td></tr>
<tr><td>U3</td><td>F</td><td>15</td><td>Glutaric academia type 1</td><td>Head pointer, SINA</td></tr>
<tr><td>U4</td><td>F</td><td colspan="3">She is not attending anymore the cerebral palsy centre</td></tr>
<tr><td>U5</td><td>M</td><td>31</td><td>Spastic quadriparetic cerebral palsy with bipolar affective disorder</td><td>Joystick</td></tr>
<tr><td>U6</td><td>M</td><td colspan="3">He was our control user, but he has lost totally his head control as he presents a degenerative prognostic</td></tr>
<tr><td>U7</td><td>M</td><td>19</td><td>Child's CP, quadriplegia, spastic-athetoid</td><td>Joystick</td></tr>
</table>

Table 4.10: CP users' profile in the usability evaluation with the final system.

Therapists evaluation

- User 4 and User 6 do not use SINA anymore. User 4 does not attend anymore the centre and User 6's physical conditions have deteriorated and now he does not have head control.

- Although User 1 was removed from the project due to his physical deterioration, he has been using SINA since he got better. He works with action/reaction Powerpoint presentations. Another alternative access system he uses are switches, he usually works with two. User 1 has got important attitudinal problems. One way for him to call someone's attention is to play the role of "bad boy", therefore sometimes when he is praised for doing something correctly; he stops doing it and acts totally different. Moreover, his physical conditions tire him, as his head is quite big for the body size, therefore certain positions where he has to hold his head, he gets tired. It is planned next year to use a support for holding his head, and a new access system will be tested. We also have to comment a problem of persistence: he sometimes gets lock in a position that can last for a few seconds. This condition occurs at every task he does until another stimulus gets him out of that persistence point. The aims of User 1 to work with SINA are more related with rehabilitation, although a way for communicating effectively with the computer is also needed. These aims are:

    - Improve his head control.
    - Widen his horizontal head motion.
    - Train this head control in all the possible movements.

  SINA is helping User 1 to reinforce his neck musculature, to dissociate his head movements from the waist and work his posture control and all possible head movements. He works with presentations of Powerpoint and action/reaction tasks, mainly working the horizontal trajectory and he is able to maintain his head up and control his movements during the whole activity without intervention of the waist movement. Therapists are introducing new flexor-extensor movements and neck diagonals and although he is able to carry them out, they are difficult for him and he gets tired. He needs help to perform them in a dissociated and controlled way.

  The hands-free interface is being useful when working in training sessions.

When he is working alone, User 1 forces the paravertebral[5] musculature and he presents arm associated reactions. This causes him a great discomfort. Moreover, his results are always influenced by his physical and mood state that are very variable.

- User 2 participated in the first phase of SINA and he continues in the project but he has also started to use a joystick with a switch for carrying out the click event. SINA helped him to work his spatial orientation which he did not control before; therefore his performance with the joystick has improved. The aim for User 2 to work with SINA is:

  - Improve his use of SINA because in the future it can offer him a more effective way of interacting with the computer. Now, he is starting to use the same applications as with the joystick.

  User 2 started using the hands-free interface with activities for training his spatial organization. Nowadays, he is using applications such as interactive stories and other applications. There are tasks that he cannot perform effectively because it is difficult to configure a profile for him. He has difficulties carrying out continuous trajectories with his head and it is difficult for him to keep his head steady, so therefore, he needs a low *Click time* setting and this can cause him to perform events when he does not want to. Depending on the task, he uses different profiles.

- User 3 uses SINA as her current access device in the computers' room and at her home. It has been proved to be up to now the best access device and therefore she abandoned the use of the joystick she held with the chin. She has fewer spams when working in front of the computer, although therapists cannot affirm if it has been the use of SINA or other reasons. The aims for User 3 to work with SINA are:

  - Generalize the use of SINA everywhere.

[5]Located along a vertebra or the vertebral column.

  - Improve the efficacy of the applications for her needs.

  User 3 is increasing her competence using SINA with all applications, although her physical state has deteriorated. It would be more functional for her to increase the size of the screen items, but she prefers to use them in a standard way. She is able to work with all the events of the graphical event toolbar and with the virtual keyboard.

- User 5 continues working with SINA and with a joystick too. SINA helps him to gain control over his head motion. His natural head position is tilted, therefore, SINA demands him to straighten his head, which does not happen with the joystick, and therefore his position is not correct, tires him and he forces the back. The aims for User 5 to work with SINA are:

  - Generalize the use of SINA everywhere.
  - Improve his head control.

  Nowadays he works some of the tasks in the computer room with SINA, but he still does not work with all the events of the event graphical toolbar. As he only uses the click event, he configures it as the initial event in his profile. Nevertheless SINA helps User 5 to keep a better posture. He has increased his resistance and he can keep his head straight for longer periods.

- User 7 is a new user, he works correctly with SINA and with a joystick, but due to his involuntary movements and the cost of the joystick he uses, the therapists and the parents prefer the use of the hands-free interface. His aim with SINA is:

  - Increase his autonomy when working with the computer.

  SINA would be a better input device for him because he presents a lack of motor and emotional control, and therefore he should have the input device out of his reach.

Tests

Tests were ran in the same computer as used with non-disabled users (13.3" monitor, screen resolution was 1280×800 pixels) and they were registered. The *Time Click* was configured for each user. Evaluation was carried out in twelve sessions during one month.

Four different tests classified in two groups were done with the cerebral palsy users (33 tasks each user):

- Group I: these two tests are images covered with black blocks and the user has to turn them in order to discover the image under them. The way of uncovering these blocks is passing over them with the cursor. The image is covered with 6x16 black blocks.
  - Test 1: the size of each block is 175×50 pixels and the screen is covered completely except for two ranges of 115 pixels on the left and right side of the screen, see Fig. 4.4. All users did 6 tests of this kind.
  - Test 2: the size of each block is 114×33 pixels and the image is centred in the middle occupying 684×528 pixels of the whole screen, see Fig. 4.5. The idea is that usually our users will have the icons and programs set in the centre of the screen with no need of approaching the corners. All users did 11 tests of this kind.
- Group II: these two tests are images covered with black blocks and the user has to turn them in order to discover the image under them. The way of uncovering these blocks is clicking on them with the cursor. The image is covered with 3x3 black blocks.
  - Test 3: the size of each block is 350×266 pixels and the screen is covered completely except for two ranges of 115 pixels, see Fig. 4.6. All users did 7 tests of this kind.
  - Test 4: the size of each block is 227×171 pixels and the image is centred in the middle occupying 681×513 pixels of the whole screen, see Fig. 4.7.

The idea is that usually our users will have the icons and programs set in the centre of the screen with no need of approaching the corners. All users did 9 tests of this kind.

Effectiveness and Efficiency

Effectiveness was measured by controlling if the user was able to finish the task without physical help, that is, without the therapist helping the user to move his head in a particular direction. Efficiency has been measured as the time users need to finish every test task.

In these experiments, efficiency results provided by several cerebral palsy users are not their most valuable measurement because many parameters interfere in the performance of a task like the initial physical and behavioural state for a particular day. In the charts presented with the timings of every user in the Annexe A, repeated tests on the same day are not ordered chronologically because there is no information added. There is no correlation between the data, that is, they don't go faster as they go practicing the test or they don't go slower because they get more tired.

Next we will see in detail the experience of the CP users in the test sessions.

- Most of the days, User 1 was not too motivated to work. This happens to him in all the activities, not just working with the computer or SINA. This is reflected in the number of tests per day. As shown in table 4.11 some days after one or two tests he was not in the mood for continuing and he just kept staring at the screen or any other part of the room without moving his head as an indicator that he was not going to participate anymore in the evaluation. In his case, one way of motivating him was to print the image he uncovered for putting it into a photo album. Moreover, when tests were number one or two, as they were long, he used to start, and after a while he stopped due to fatigue or mood. The therapist was continuously interacting with the user, talking to him about the image hidden or joking with it, motivating him, and sometimes he continued working. When analyzing the duration of the tasks, we have to

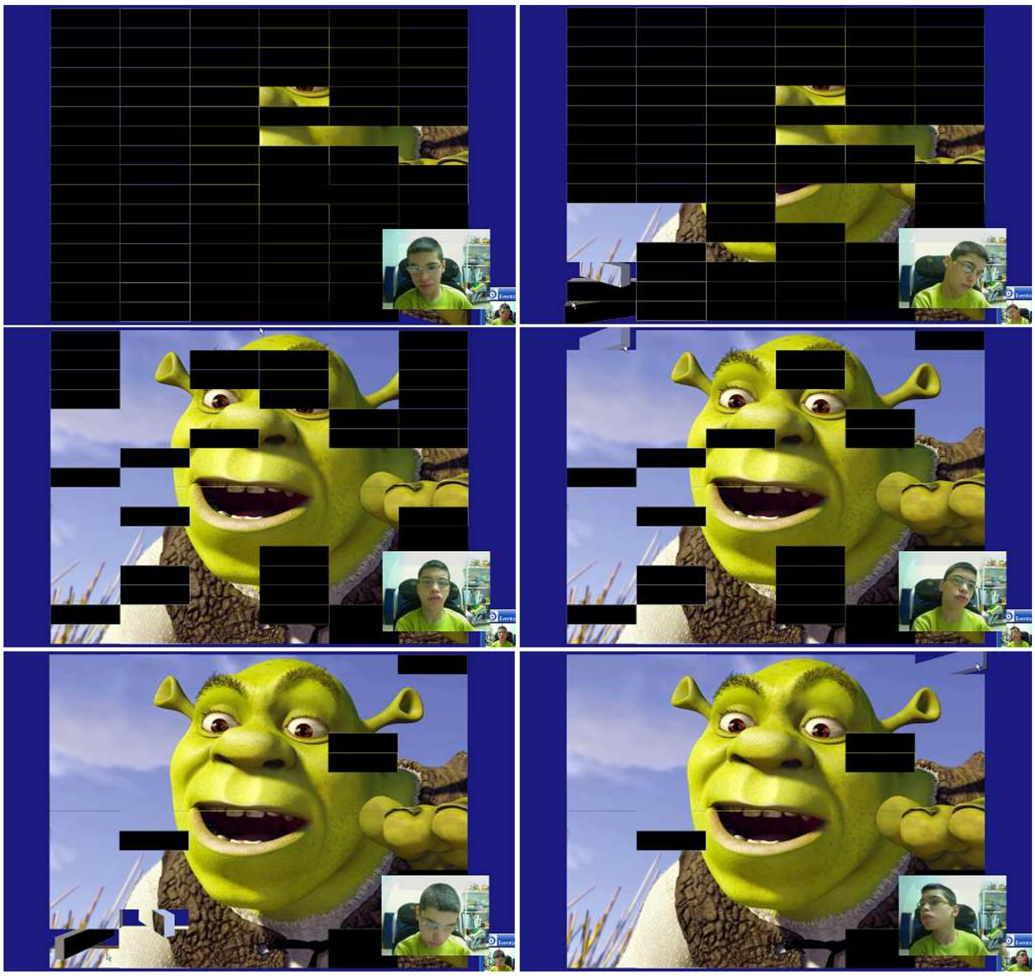


Figure 4.4: Test 1.

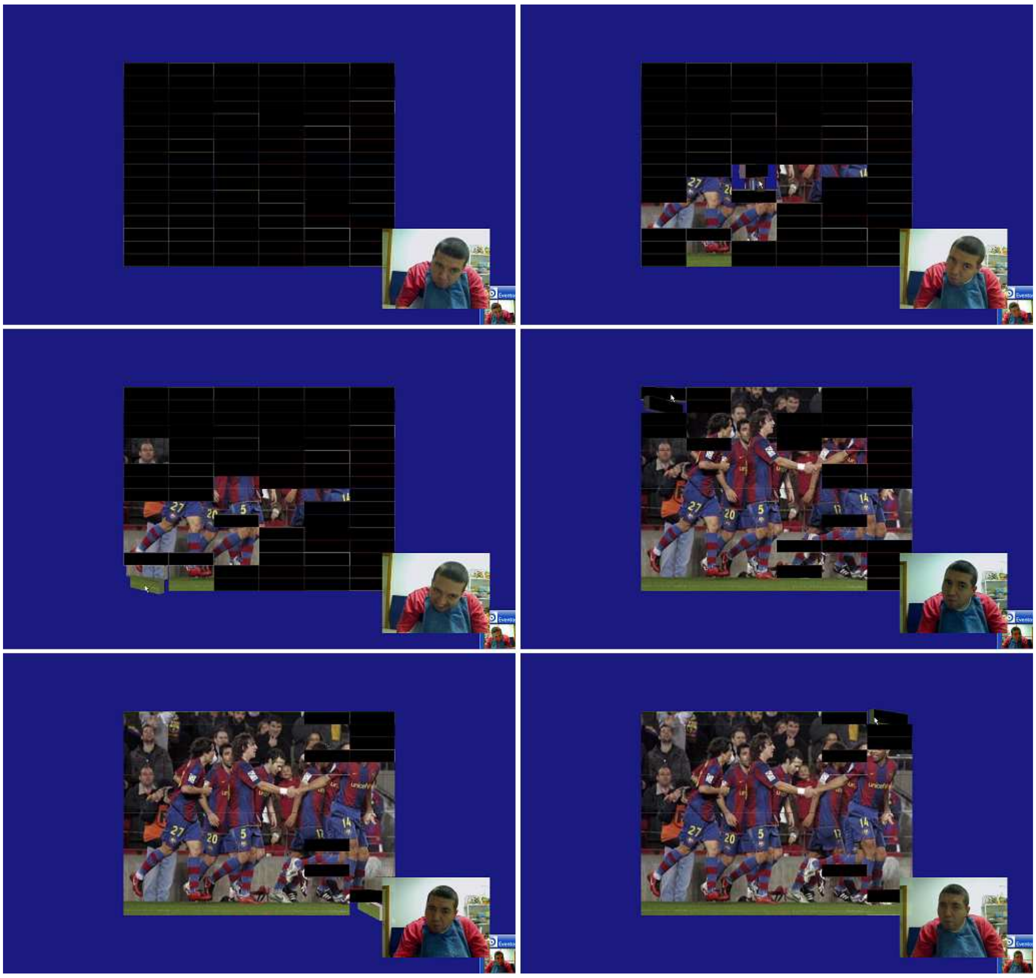


Figure 4.5: Test 2.

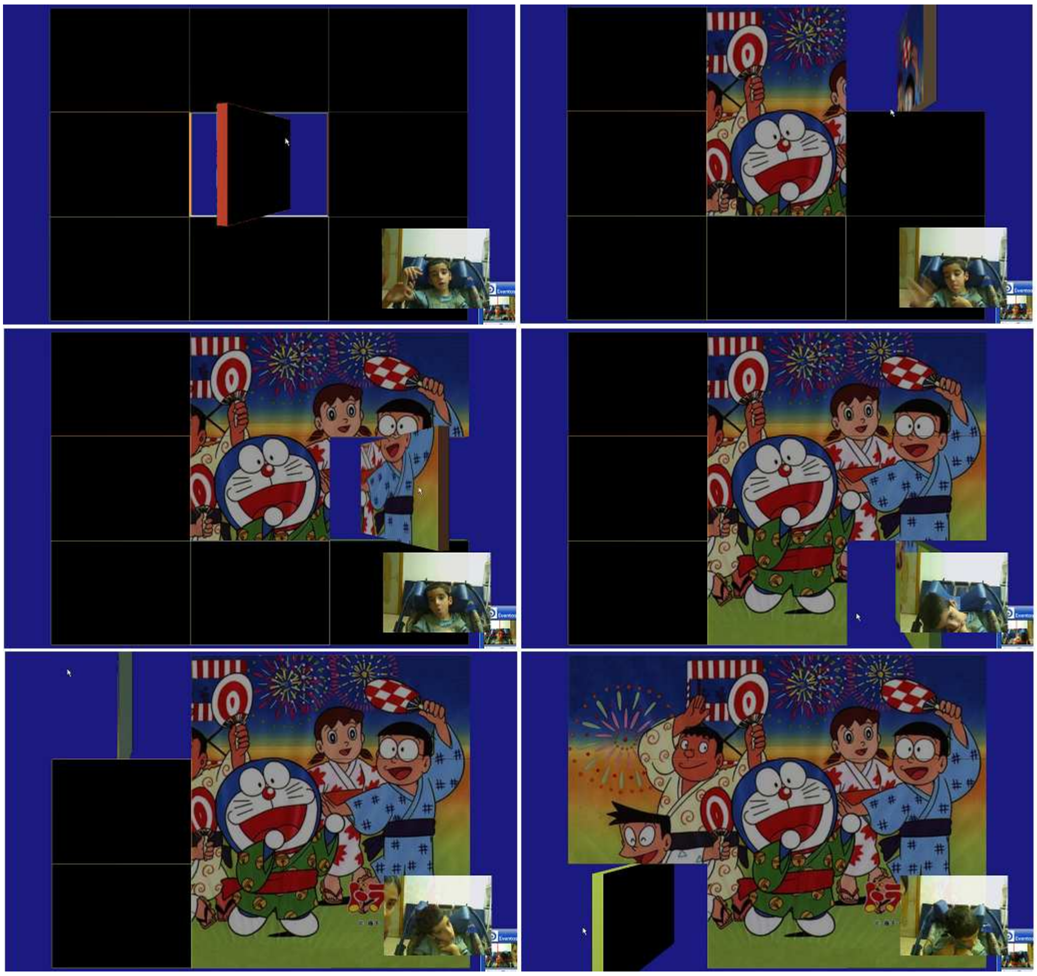


Figure 4.6: Test 3.

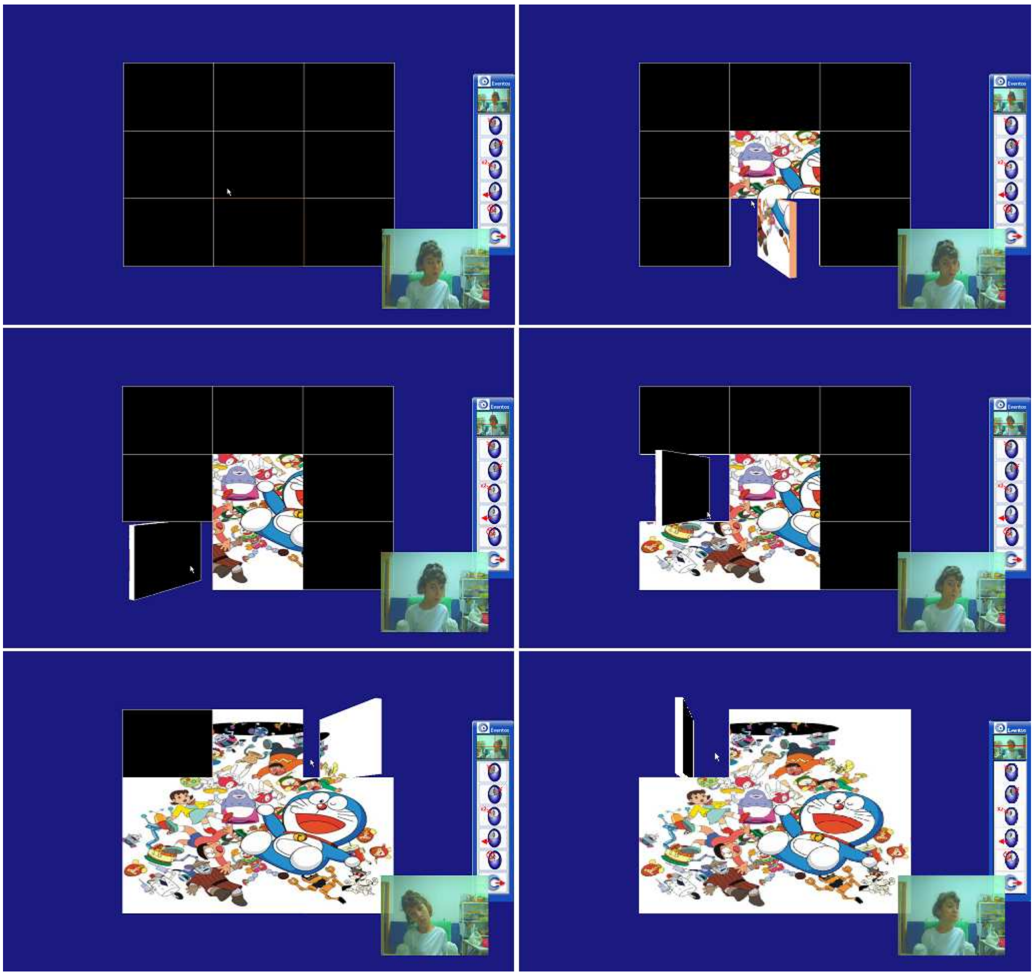


Figure 4.7: Test 4.

take into account that in that value, all the stops are counted, although there is no pattern that reflects improvement or tendency along the days.

The individual results per day and test can be seen in Annexe A. User 1 did not finish successfully without help any test 1 and several of test 2 due to fatigue or because he did not want to work. The tasks he did not finish are marked in his charts in Annexe A with red colour. The therapist says that he could finish the activities but he did not want to collaborate. This fact can be contrasted because several days he could perform correctly Test 2. Test 3 and 4, as they were shorter, he carried them out successfully with effectiveness.

- User 2 was quite constant in his results and tests per day (see table 4.11), except for several tasks that he was not too motivated and he was just collaborating because he understood that it was an evaluation but he did not make much effort. For example on the 8th June his results move away from the average.

  We have to remark that user 2 has problems with spatial orientation and if the therapist helps him indicating directions, then he needs less time to finish a task. User 2 was able to finish successfully all the tasks, therefore the effectiveness is correct. His body movements were jerky or smooth depending on the day.

- User 3 is with no doubt the user which performs better and faster all the tasks. She carries out the tasks with organization and following lines and her movements are smooth. She has no problem using the interface and she does not present cognitive or behavioural problems. She is regular with her performance and timings only vary depending on the involuntary movement that she presents. This year she presents an important involuntary movement, that can last from seconds to minutes depending on how long she needs to relax and it is included in the timing of the task. She has missed many sessions due to activities out of the centre or due to health problems, but she was able to perform in less days and with effectiveness the same amount of tasks as the other users, see Table 4.11.

- User 5's performance was also very dependent on his physical and mood state, when he was tired he did no want to work and therefore, on two days he just did two tasks, when usually he carried out from 4 to 7 tasks per day, see Table 4.11. Usually he was motivated. Timings of a same task, even if they are done on the same day are not correlated. Although in the long tasks of Test 1 and 2, the first time he performed them is when his efficiency was better. He always performed the tasks with effectiveness. His body movements were rough or smooth depending on the day.

- User 7's effectiveness was always correct. He could finish all the tasks. Therapists don't know much what his interests are, but he usually looked motivated with any image we put for him. Even some days he did 9 and 10 tasks, see Table 4.11. His body movements are jerky but he could perform with effectiveness all the tests. Results from different days don't look to keep much relation, but approximately the first time he performed a task it is when his efficiency was better.

Date	N^o tests U1	N^o tests U2	N^o tests U3	N^o tests U5	N^o tests U7
18/05/2009	2	2	3	4	0
20/05/2009	3	2	2	2	3
21/05/2009	2	2	3	6	4
25/05/2009	4	3	0	5	4
27/05/2009	1	5	10	8	0
28/05/2009	2	5	0	2	0
03/06/2009	0	5	0	6	0
08/06/2009	8	4	6	0	10
10/06/2009	6	0	0	0	9
11/06/2009	4	0	0	0	3
16/06/2009	1	5	0	0	0
17/06/2009	0	0	9	0	0

Table 4.11: Number of tests per day for each user.

Concluding we can observe the averages of every task for each user in Table 4.12. Users are very different among them, therefore results differ greatly, but each user is congruent with his or her performances in the four tests. Our hypothesis that centring the image in the screen would be easier for the users, it has proved not to be true, as timings are similar for every group of tests. This can be explained because, although the region to uncover is smaller and more centred, the blocks are smaller and they need more accuracy. Finally, we want to highlight that all users have been able to perform events and are able to move around all the screen.

Test	User 1	User 2	User 3	User 5	user 7
Test 1	6:20	4:23	1:46	5:16	3:02
Test 2	7:31	3:17	1:40	5:26	2:53
Test 3	2:27	1:10	0:44	1:20	1:10
Test 4	2:42	1:50	0:57	1:24	1:20

Table 4.12: User's timing mean per test.

It is important to remark that no trajectory studies have been done as recommended by MacKenzie et al [62] and Keates et al [54]. We presented a task where they had to click on a particular block, this one vanished and another block appeared and they had to click on it. They had to repeat the process six times while we were saving all the cursor's position for analyzing the trajectories. Results were not meaningful at all, as none of them except User 3 have continuous movements. Many present erratic movements and they don't follow any strategy to reach a target. Therapists agreed that the task was not significant for these users and moreover, they told us that similar results would appear if we analyzed paths for the alternative devices like the joystick.

Satisfaction

At the end of each day of work with a user, a satisfaction questionnaire was filled.

We prepared the questionnarie following the PedsQl recommendations for cerebral palsy users aged between 5 and 7 [111]. This method consists in showing a template with three faces: a smiling one, a neutral one and a frowning one when asking the question. Questions a prepared in a way that the possible answers correspond with the faces: it is not a problem, it may sometimes be a problem or it is a problem.

In our case, the faces' pattern 4.8 was finally not used because the therapists have worked with the users for a long time and they know how to interpret their signs or sounds. If there was any doubt, all of them carry cards of patterns with answers that they already work with and know and they just had to point at them. Although we did not use it, it is important to prepare a general satisfaction questionnaire for facing other situations where there is not a close relationship between the user and the interviewer.

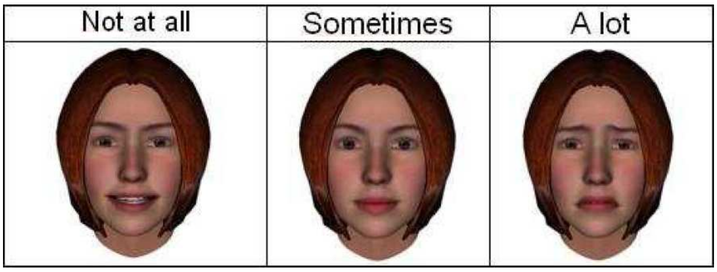


Figure 4.8: Faces pattern.

The questionnaire [6] is divided in three sections:

The first section includes four very simple questions for the user:

1. Q1: Is it difficult to understand the task?

2. Q2: Is it difficult to use the hands-free interface?

3. Q3: Is the task boring?

4. Q4: Are you tired after using the hands-free interface?

We wanted to obtain information on how the user felt using the system and carrying out a task, but we did not want the user to get tired by asking many questions.

The second section is for the therapist to answer and questions are related to the user working with the system, to find out if he understands how to click with the interface or how to move the cursor. There are also questions on the user's fatigue

[6] The complete questionnaire is in Annexe D

(mental and physical), although the user has answered us personally, we also want to confirm with the therapists opinion. Last, questions on the user's posture and involuntary movements are also included.

The third section is focused on more technical details like the accuracy or speed, and general aspects such as comfort and general impression of the use of the interface for a user in particular. These questions can be answered by the therapist or by the evaluator.

In the Annexe A in the satisfaction section the answers for questions 1, 2, 3 and 4 addressed to the users are shown. Lower values indicate higher satisfaction.

There is a general answer to the first question (Q1: Is it difficult to understand the task?) for all five users. They understand the tasks presented and what is the objective. They worked motion and clicking in the educational programs, so therefore, we just had to specify at the beginning of each test what was the aim.

To the question "Q3: Is the task boring?" the answer was also unanimous. They all commented that the task was not boring. We changed the hidden image in every test and we tried to motivate them with images that were of their liking. Although, it is true that sometimes users were not in the mood for working. This fact is captured in the number of tests done per day. Users 3 and 7 did not present this behaviour in any of the sessions. User 2 and 4 were in this mood during several days, but User 1 presented this behaviour almost daily at some moments of the session.

Question two was related to the difficulty in using the interface. For some users which have less head control or because they present dissociate head motion it can be difficult to reach to particular places of the screen. For example User 1 has difficulties turning his head to the left side, and therefore that zone was many times the last part to uncover. Moreover, some of them repeat the same head movement always, the same trajectory, and they go through the same blocks several times without uncovering neighbour blocks.

This question is related to the fourth and last question we did to our users, if they were tired. Again, users with more difficulty controlling their head or User 1 whose head size is big comparing it to his body got tired if sessions were long. Performance differed when before the session, they had activities such as physiotherapy sessions or being in the swinmming pool where the water and ambient temperature is high and their muscles were relaxed.

Answers given by the therapists in the second section of the questionnaire coincide with the ones coming from the users for those questions regarding the fatigue and the understanding of the tasks using SINA. The relevant information extracted is the improvement of the general body posture of several users (when using the interface); SINA demands the user to keep himself more or less straight facing the camera and the movements are not too demanding, therefore it is less tiring than other systems and the user sits in a better posture. For example, User 3 does not get tired at all with SINA, but when she uses a head wand, she really forces her body posture.

Finally, the third block questions have not contributed with new information. Users can work with the interface after a correct configuration of SINA settings. The facial features recognition is fast when the user looks straight to the camera (in some cases they needed help) and if the nose gets lost, there is a reason behind it like if the user looks down too much and creates an important shade. Then he just has to look up and the system recovers.

Comparisons with other input devices

Comparisons between SINA and other input devices have been done. Each user performed Test 2 and Test 4 with their other alternative access system except User 1 which uses switches and it is not a pointing device. In Table 4.13 the timings are indicated.

All of them perform better times with SINA considering the average of all tests 2 and 4 (11- Tests 2 and 9-Tests 4) and the timing of the first time they did Test 2 and Test 4.

They just did the test once with the alternative system, therefore we show the timing for the first time using SINA in Test 2 and 4. When they performed the tasks with the alternative deviece, all of them knew the task and only User 3 uses SINA in all her activities. Users 2 and 7 still work with the joystick in the computers' room and User 5 alternates.

Test	User	SINA Timing (mean)	SINA Timing (first test)	Alternative Device	Timing
Test 2	User 2	3m17s	1m48s	Joystick	7m01s
Test 4	User 2	1m50s	1m19s	Joystick+switch	3m20s
Test 2	User 3	1m40s	1m21s	Head wand+keyguard	4m04s
Test 4	User 3	57s	23s	Head wand+keyguard	1m44s
Test 2	User 5	5m26s	7m59s	Joystick	8m24s
Test 4	User 5	1m25s	2m11s	Joystick+switch	3m53s
Test 2	User 7	2m53s	2m15s	Joystick	3m54s
Test 4	User 7	1m2s	1m23s	Joystick+switch	2m48s

Table 4.13: Devices comparison.

Problems coming from the use of joysticks are that it has to be well held on the table because they present involuntary movements that can displace the joystick. Users using the joystick have not got smooth nor continuous movements with their hand and arm, and therefore they have to reposition their hand every now and then. Moreover, the other hand interferes with the movement of the hand controlling the device.

For User 3, when she starts working with the head wand and the keyguard the devices are well placed, the problem can come if she moves the keyboard or keyguard with the head wand, and then reaching to the keys may be very complicated. User 3 does not work with the head wand as often as she used to, as now her input device is the hands-free interface.

User 2 when working with SINA controls his involuntary face and mouth movements because he has to be more concentrated to keep steady the cursor in a particular position, but with the joystick this is not necessary so he in continuously moving his mouth.

User 5 adopts a very uncomfortable posture when working with the joystick that causes him fatigue as his neck is totally bended looking down. He has to be continuously looking down at the joystick and looking up to the screen.

User 7 does not present so many posture differences or involuntary movements when working with one device or the other.

Finally, after finishing the test with the alternative system, we ask the users about their preference. Results are detailed in Table 4.14. Three users prefer SINA rather than the other system, but the device preference is very related to the system that demands less effort.

User	Preference	Fatigue
User 2	Joystick	SINA
User 3	SINA	Head wand
User 5	SINA	Joystick
User 7	SINA	Joystick

Table 4.14: Devices preference.

Chapter 5

Conclusions

Every day you may make progress. Every step may be fruitful. Yet there will stretch out before you an ever-lengthening, ever-ascending, ever-improving path. You know you will never get to the end of the journey. But this, so far from discouraging, only adds to the joy and glory of the climb.

Sir Winston Churchill.

The search for more natural and multimodal forms of interaction with computers or systems is an aim to achieve. Vision-based interfaces can offer appealing solutions to introduce non-intrusive systems for interacting by means of processing the images in search of gestures or tracking.

Computer vision can be suitable for developing usable user interfaces in order to achieve human-computer interaction. Our work has shown that the developed technology can be taken out of the laboratoy into real scenarios. The research conducted has contributed with an effective, efficient and satisfactory hands-free interface for users with motion difficulties in the upper body limbs, who could not use correctly standard devices. A vision-based interface has been presented and it works with a new mixture of several computer vision techniques, where some of them have been improved and enhanced to reach more stability and robustness in face tracking. The interface presented is able control the cursor's motion and execute the mouse's events.

Computer vision in our particular case offers unencumbered data acquisition capabilities, it is a low cost system because we use a webcam, and we don't use special lighting or background.

Moreover, as commented before, one of the reasons for discontinuance (abandonement) of assistive technologies is the dissatisfaction. This can be avoided if we focus soon on the users, we do multiple evaluations all along the development process and use a prototyping system in order to incorporate improvements and modifications as they go appearing.

The research describes how usability affected the product design when applying it at early stages of the software developing. We have presented the development process where usability has been included in the overall process of our software development and we have integrated the end-users into the evaluation of prototypes in order to improve and include the user's needs and requirements at early stages of the development.

Usually the research papers on this kind of vision-based interfaces, present the final product together (or not) with an evaluation, sometimes even without the real intended audience of the system. None of them, up to our acknowledgment, described the process of improvements done to the interface due to the user's feedback, therefore, we want to contribute with a possible framework to follow when implementing vision-based interfaces.

Specifically, our hands-free interface has been tested with non-disabled users and with users with cerebral palsy. It does not exist a common evaluation procedure for hands-free interfaces based in computer vision with disabled users. We have to take into account that cerebral palsy users are very special users whose capabilities differ greatly among them, and a study of each user individually has to be done in order to choose the best device for him.

Results studying the evaluation with the real users have shown the potential and benefits of this hands-free interface. It has been proven to be a suitable system for diverse reasons: low cost, allows a correct body posture, tasks can be carried out successfully and in several cases even faster than with other devices and satisfaction level among the users is high. Due to the good results, we hope to have stimulated the interest in further exploration of vision-based interfaces as an interaction modality for disabled users.

Furthermore, the experience have shown that SINA, besides being an access device, could be used for rehabilitation purposes as several users have improved their head control, and it would be an interesting field to study. Moreover, new metrics should be applied to evaluate effectiveness, efficiency, satisfaction and other parameters such as assistance needed or mental/physical effort.

Finally, we would like to comment that once finished the system development, the use of the hands-free interface has been extended to six more centres and the final release of the interface is available under a freeware license in the Web page http://sina.uib.es/. This will allow us to have users around the world testing the application and we will be able to improve the results by analyzing their reports.

5.1 Publications and contributions

As part of a scientific method and research process, the discovered improvements should be published and accessible for the research community, which can correct or take advantage of the acquired experience. The papers consequence of the research are detailed next.

5.1.1 Journals

- Manresa-Yee, C, Ponsa, P., Varona, J. and Perales, F.J. (2009). *Improving the development of vision-based interfaces with usability.* Journal of Systems and Software. ISSN: 0164-1212. (Submitted 2009)

- Varona, J., Manresa-Yee, C, and Perales, F.J. (2008), *Hands-free vision-based interface for computer accessibility*, Journal of Network and Computer Applications, Volume 31 , Issue 4 (November 2008), pp. 357-374 , ISSN:1084-8045

- Cerezo, E., Hupont, I. Manresa-Yee, C., Varona, J., Baldassarri, S., Perales, F. J. and Serón, F. (2007). *Real-Time Facial Expression Recognition for Natural*

Interaction, Lecture Notes in Computer Science 4478, IbPRIA 2007, pp. 40-47, 2007. ISSN: 0302-9743

- Manresa-Yee, C, Varona, J. and Perales, F.J. (2006). *Towards hands-free interfaces based on real-time robust facial gesture recognition.* Lecture Notes in Computer Science 4069, AMDO'06, pp. 504-513, 2006. ISSN: 0302-9743

- Manresa-Yee, C, Varona, Mas, R. J. and Perales, F.J. (2005). *Hand Tracking and Gesture Recognition for Human-Computer Interaction*, Electronic Letters on Computer Vision and Image Analysis 5(3):96-104. ISSN: 1577-5097

5.1.2 Books

- Perales, F.J. , Muntaner, J.J, Varona, J., Negre, F., and Manresa-Yee, C, (2009), *Sistema de interacción natural avanzado. (El ordenador al alcance de todos).* ISBN: 978-84-613-1740-0

5.1.3 Proceedings

- Ponsa, P.; Díaz, M.; Manresa-Yee, Batlle, D. and Varona, J. (2009) *Assessment of the use of a human-computer vision interaction framework.* Proceedings HSI09. pp. 434-441, ISBN: 978-1-4244-3960-7

- Ponsa, P.; Díaz, M.; Manresa-Yee, C.; Amante, B. (2008), *Diseño ergonómico de interfaz gráfica y uso de interfazde manos libres en simulación de tareas domóticas*, Proceedings Interaccion 2008, pp 197-206, ISBN: 978-84-691-3871-7

- Manresa-Yee, C, Varona, J. and Perales, F.J., Negre, F., a,d Muntaner, J.J. (2008), *Experiences using a hands-free interface.* Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility pp. 261-262 ISBN: 978-1-59593-976-0

- Manresa-Yee, C, Varona, J. and Perales, F.J. (2008). *On the Evaluation of a Face Vision-Based Interface.* Proceedings Tracking Humans for the Evaluation of their Motion in Image Sequences. THEMIS'2008, pp. 109-116, ISBN 13: 978-84-935251-9

- Muntaner, J.J., Perales, F.J, Negre, F., Varona, J. and Manresa-Yee, C, *Sistema de Interacción Natural Avanzado (SINA): Proceso de mejora y ajuste para usuarios con parálisis cerebral y esclerosis múltiple.* Proceedings Tecnoneet 08, pp145-157, ISBN:978-84-96997-02-8

- Manresa-Yee, C, Varona, J. and Perales, F.J. (2006). *Face-Based Perceptual Interface for Computer-Human Interaction.* Proceedings WSCG'2006. pp. 93-100, ISBN 80-86943-05-4

5.1.4 Awards

- Premio del Consell Econòmic Balear al proyecto SINA (2008)

- II Premio Fundetec 2006: 'Mejor Proyecto de Entidad No Lucrativa dirigido a Pymes, Micropymes y/o autónomos' al proyecto HeadDev (2006)

5.1.5 Projects

In addition, the techniques and methodologies developed have been used in a large set of projects:

- *Prototipos de Interacción Natural mediante Interfaces Enactivas basadas en Entradas Visuales* (2007-2010), Ministerio de Educación y Ciencia, TIN2007-67896 , IP: Javier Varona Gomez

- *Sistema de Interacción Natural Avanzado (SINA)* (2007-2009), Govern de les Illes Balears, Fundación IBIT Illes Balears Innovació Tecnològica, IP: Francisco J. Perales, Joan Jordi Muntaner

- *Diseño de un sistema de reconstrucción 3d mediante cámaras estereoscópicas y luz Estructurada (renovación)* (2008), AECI, A/9391/07 IP: Maria José Abásolo

- *Diseño de un sistema de reconstrucción 3d mediante cámaras estereoscópicas y luz estructurada* (2007) AECI, A/7155/06 IP: Maria José Abásolo

- *Integración de Escenarios Virtuales con Agentes Inteligentes 3D (INEVAI3D)* (2004-2007), Ministerio de Ciencia y Tecnologí, TIN2004-07926, IP: Francisco Jose Perales Lopez

- *HUMODAN.- An automatic human model animation environment for augmented reality interaction* (2002-2005), Comunidad Económica Europea, IST-2001-32202, IP: Francisco J. Perales López

- *Análisis y Síntesis del Movimiento Humano Mediante Técnicas de Visión y Animación por Ordenador* (2002-2004) Ministerio de Ciencia y Tecnología, CICYT TIC2001-0931, IP: Francisco J. Perales López

5.1.6 Research placements

- IPAB, Institute of Perception, Action and Behaviour Edinburgh. Great Britain. From the 16^{th} June 2008, to the 23^{rd} September 2008.

- Laboratorio de Sistemas. Multimedia, Animación y Realidad Virtual, Santiago de Compostela. Spain. From the 1^{st} September 2006, to the 30^{th} September 2006, from the 29^{th} January 2007, to the 29^{th} February 2007 and from the 1^{st} July 2007, to the 31^{st} July 2007

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Appendix A

Usability evaluation. Users' individual data

A.1 Non-disabled users' data

A.1.1 ISO 9241-9 Throughput

A.1.2 MacKenzie's parameters

User	MT(ms)		Error(%)		TP(bits/s)		First device
Us1	3419	3045	0	0.79	0.7695	0.7855	Crea
Us2	2814	2723	0.79	0.79	0.8841	0.8407	Sina
Us3	2948	1490	0.79	0	0.8621	0,8567	Sina
Us4	2396	2723	0.79	2.38	0.8522	0.8205	Sina
Us5	2830	2789	1.59	1.59	0.8944	0.7829	Sina
Us6	2740	2623	0	0.79	0.9439	0.9007	Crea
Us7	2641	2598	0	0	0.9627	0.9145	Sina
Us8	2924	3055	0.79	0.79	0.917	0.8754	Sina
Us9	2879	2603	0	0	0.8772	0.8821	Crea
Us10	2870	2790	0.79	0	0.8953	0.8378	Crea

Table A.1: Individual values for movement time, error rate and Fitts throughput.

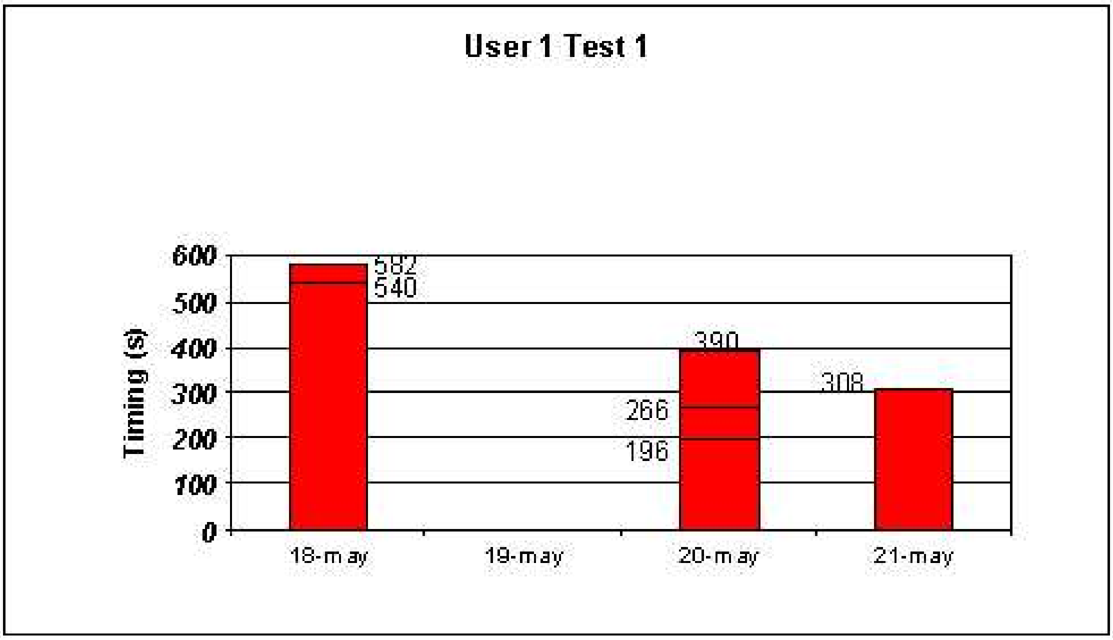
User	Device	TRE	TAC	MDC	ODC	MV	ME	MO
Us1	Sina	1.16	2.31	6.17	2.35	17.94	18.18	-4.33
Us1	Crea	1.30	1.93	4.22	2.29	18.45	18.33	-4.88
Us2	Sina	1.03	1.80	4.85	1.48	10.45	12.11	0.54
Us2	Crea	1.29	1.80	4.75	2.27	16.03	17.55	-1.50
Us3	Sina	1.10	2.35	5.39	1.38	12.11	11.76	-1.56
Us3	Crea	1.09	1.71	4.27	1.16	11.39	12.30	-0.47
Us4	Sina	1.10	1.84	4.91	2.03	15.01	15.74	-2.00
Us4	Crea	1.34	1.41	4.34	1.90	15.72	18.50	-2.39
Us5	Sina	1.20	1.99	5.05	2.10	12.93	13.10	-1.72
Us5	Crea	1.29	1.94	4.10	2.05	17.52	17.83	-1.27
Us6	Sina	1.03	2.01	5.29	1.34	8.97	10.26	0.00
Us6	Crea	1.33	1.87	4.65	2.46	15.52	16.35	-4.26
Us7	Sina	1.02	1.78	5.07	1.29	8.34	9.39	0.33
Us7	Crea	1.31	1.61	4.69	2.00	15.63	17.46	-1.79
Us8	Sina	1.15	1.90	4.77	1.88	12.66	14.00	-0.88
Us8	Crea	1.50	2.28	5.70	3.24	19.21	17.23	-1.39
Us9	Sina	1.16	1.97	4.53	2.11	14.49	14.73	-1.20
Us9	Crea	1.22	1.37	4.10	2.20	16.19	18.00	-1.71
Us10	Sina	1.05	1.79	5.92	1.46	9.69	11.64	-0.08
Us10	Crea	1.30	2.07	5.61	3.05	16.44	16.74	-0.24

Table A.2: Values for MacKenzie's path studies for each user.

A.2 Disabled users' data

A.2.1 Effectiveness and efficiency tests

In the next charts, the timings and the dates they were carried out are shown for each user performing the four tests. Red colour indicates that the task was not successfully finished. Timings of a test done the same day, are not ordered chronologically.



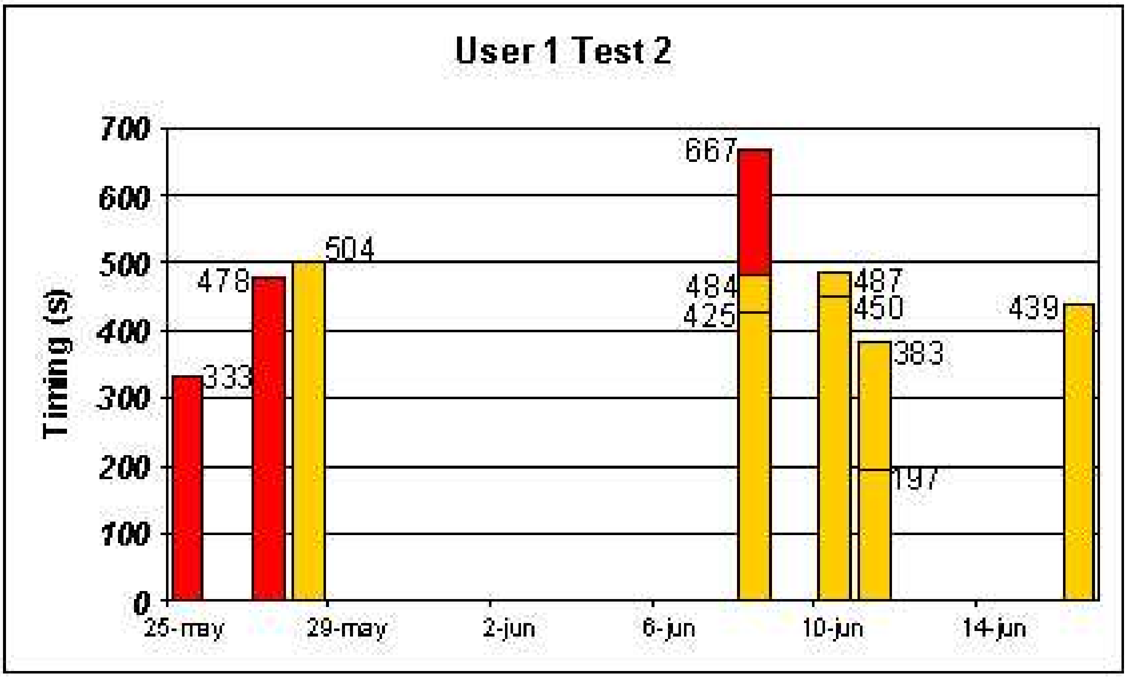
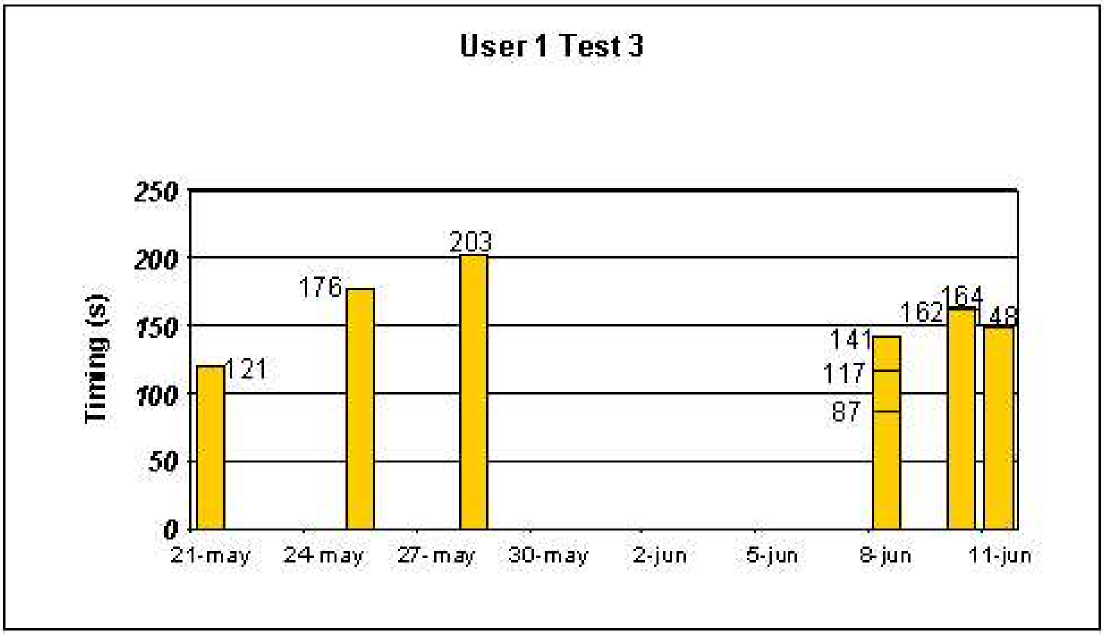


Table A.3: Efficiency tests: Test 1 and 2 for User 1. Red colour indicates tasks he did not finish



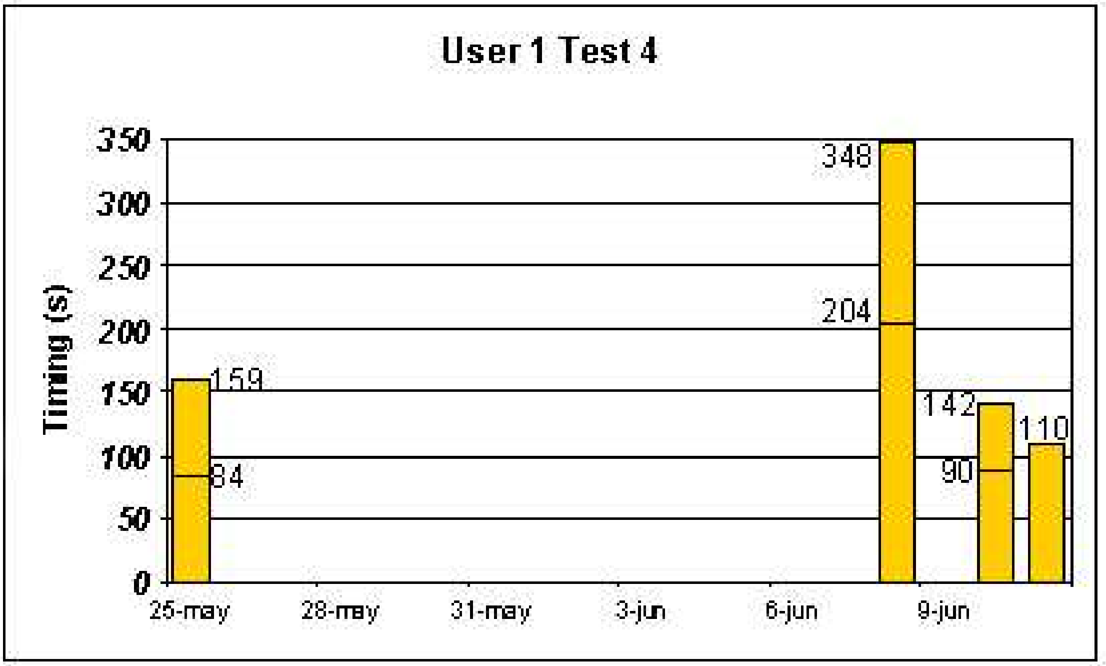
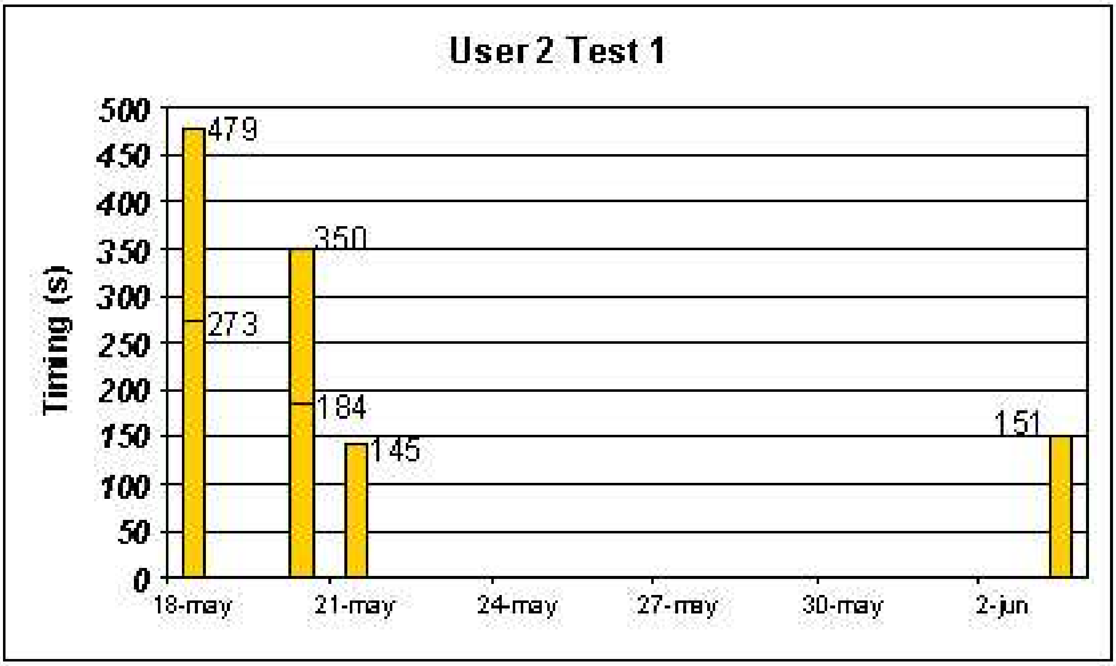


Table A.4: Efficiency tests: Test 3 and 4 for User 1.



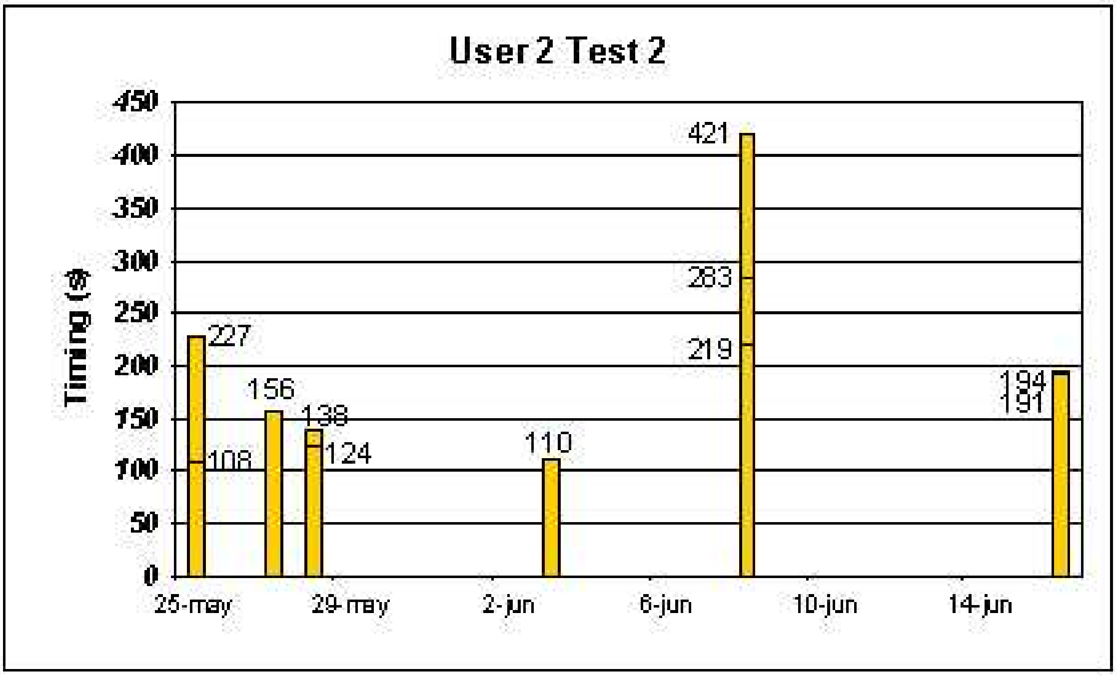
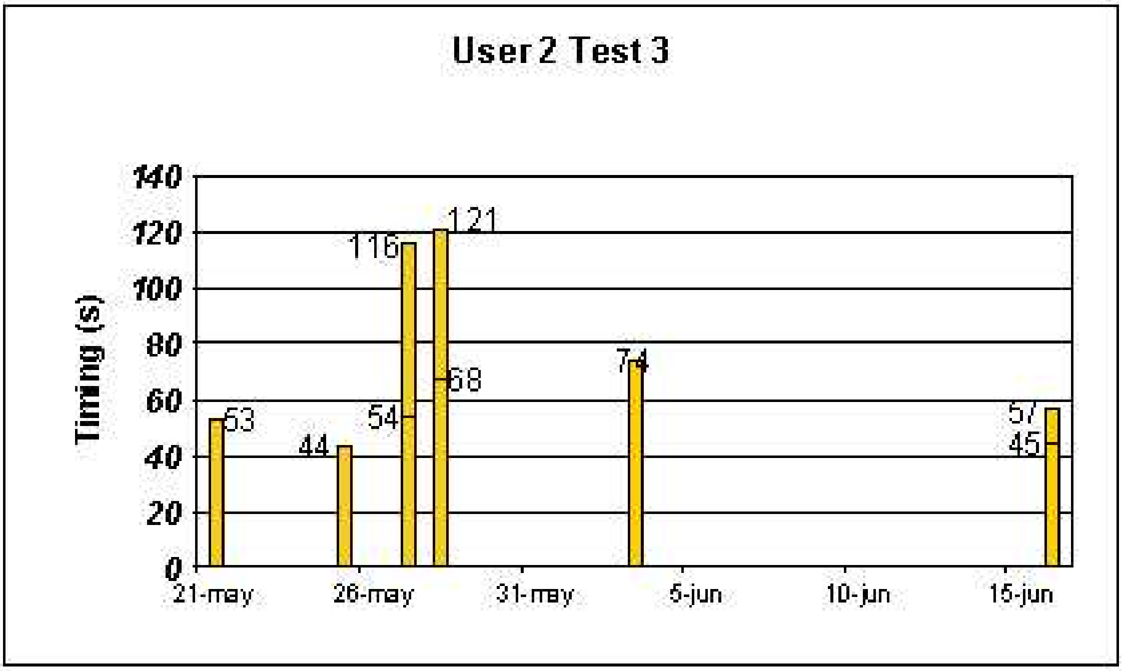


Table A.5: Efficiency tests: Test 1 and 2 for User 2.



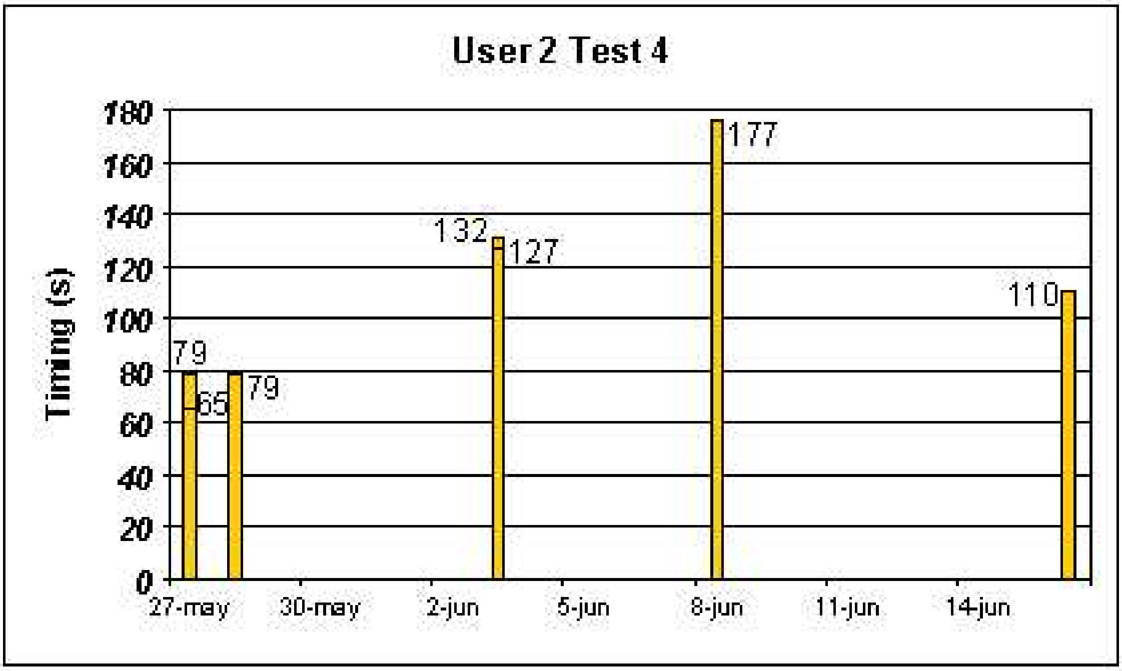
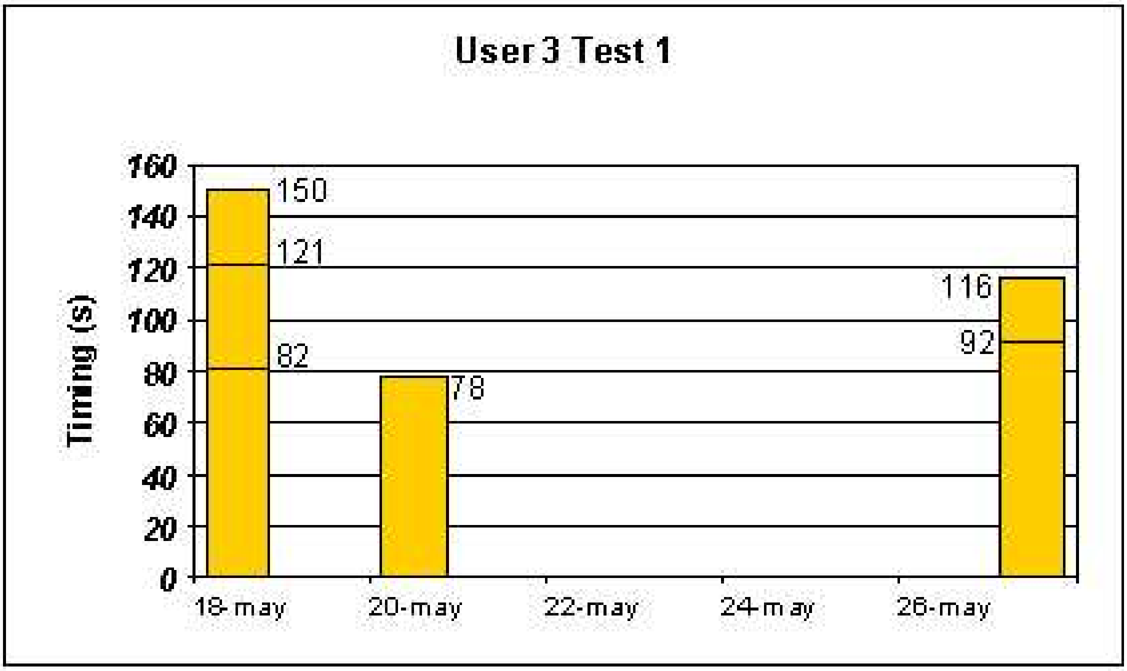


Table A.6: Efficiency tests: Test 3 and 4 for User 2.



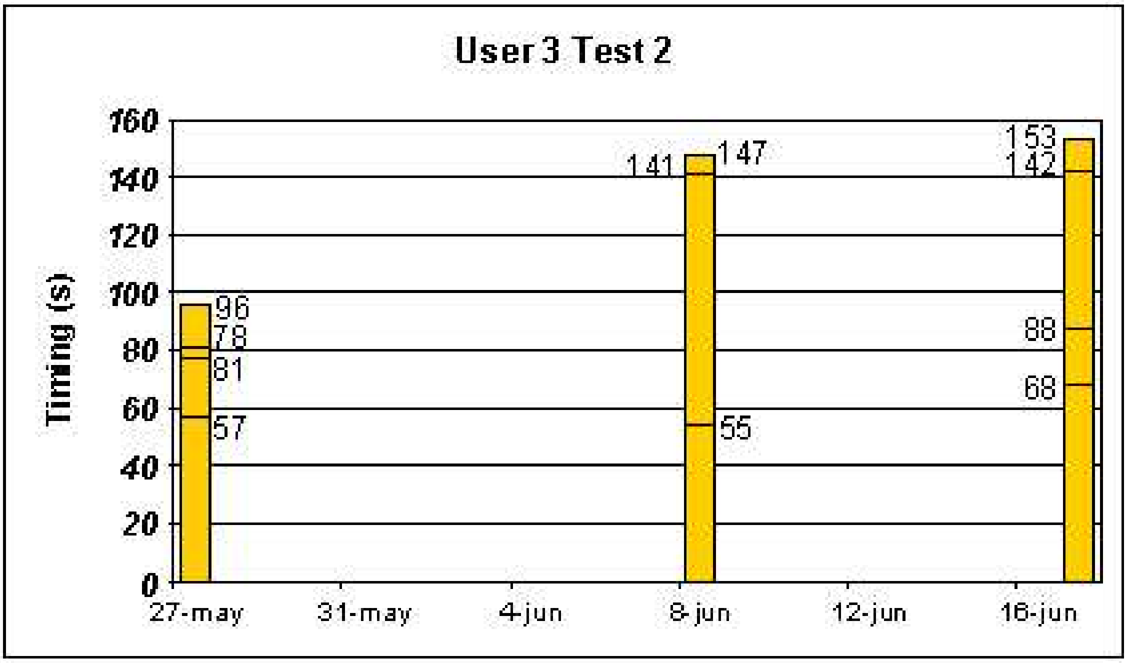
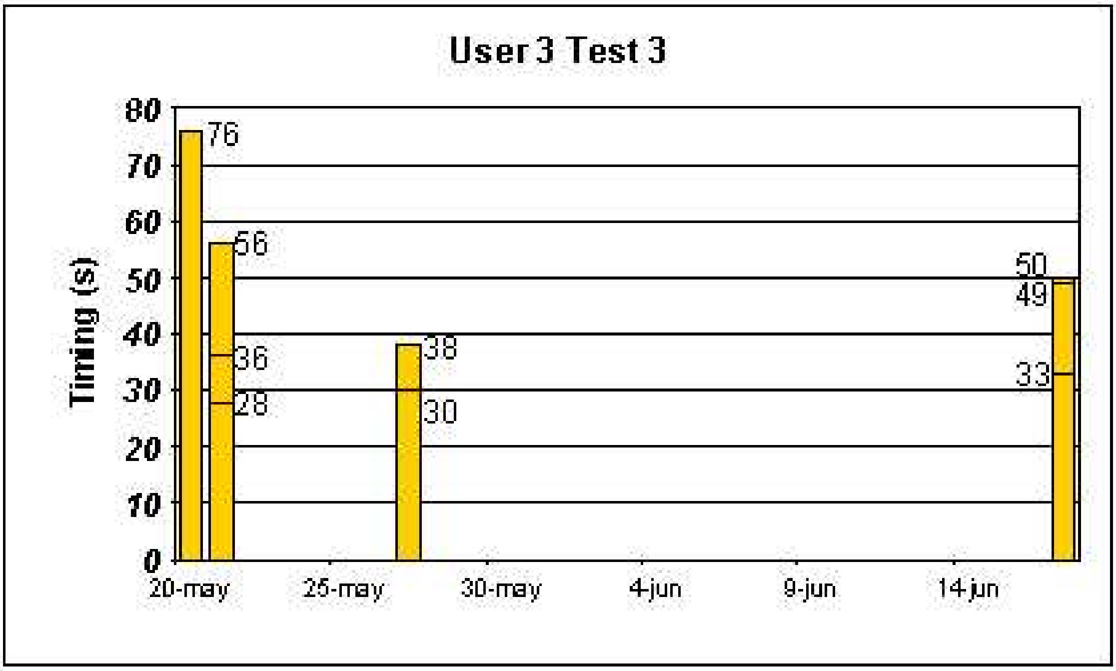


Table A.7: Efficiency tests: Test 1 and 2 for User 3.



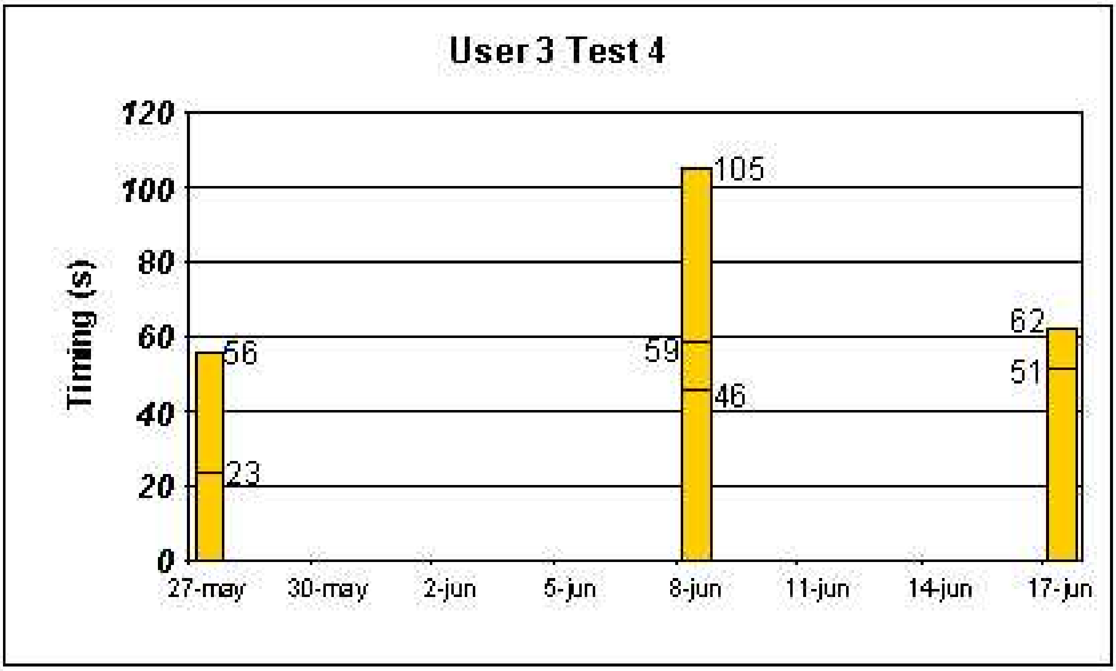
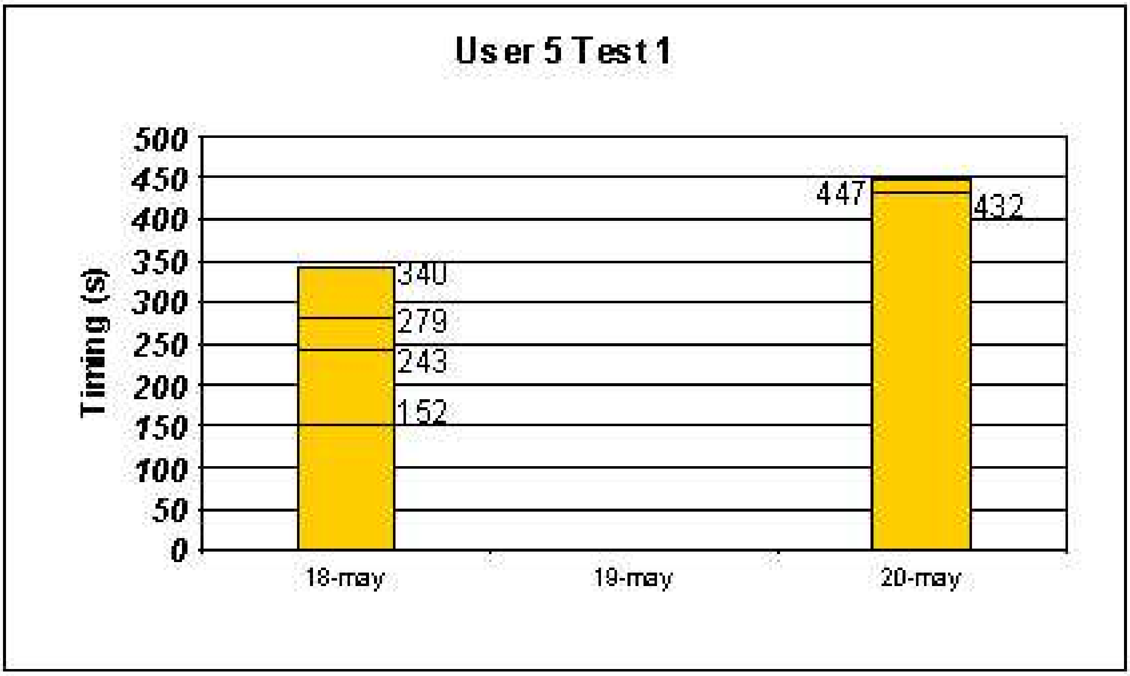


Table A.8: Efficiency tests: Test 3 and 4 for User 3.



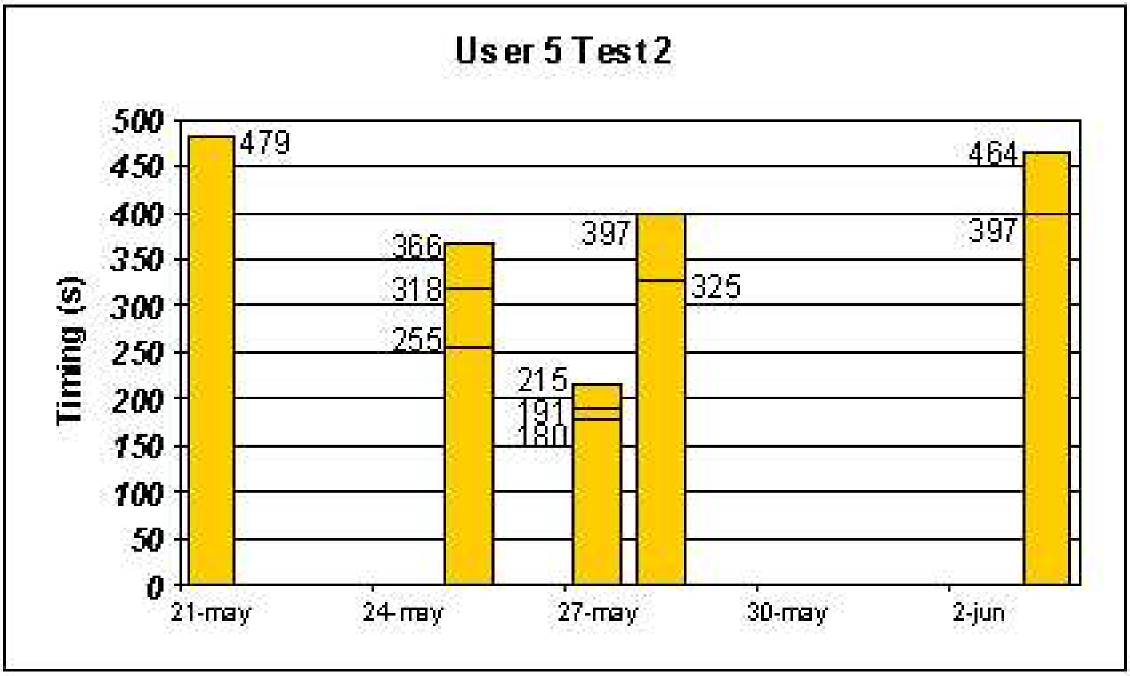
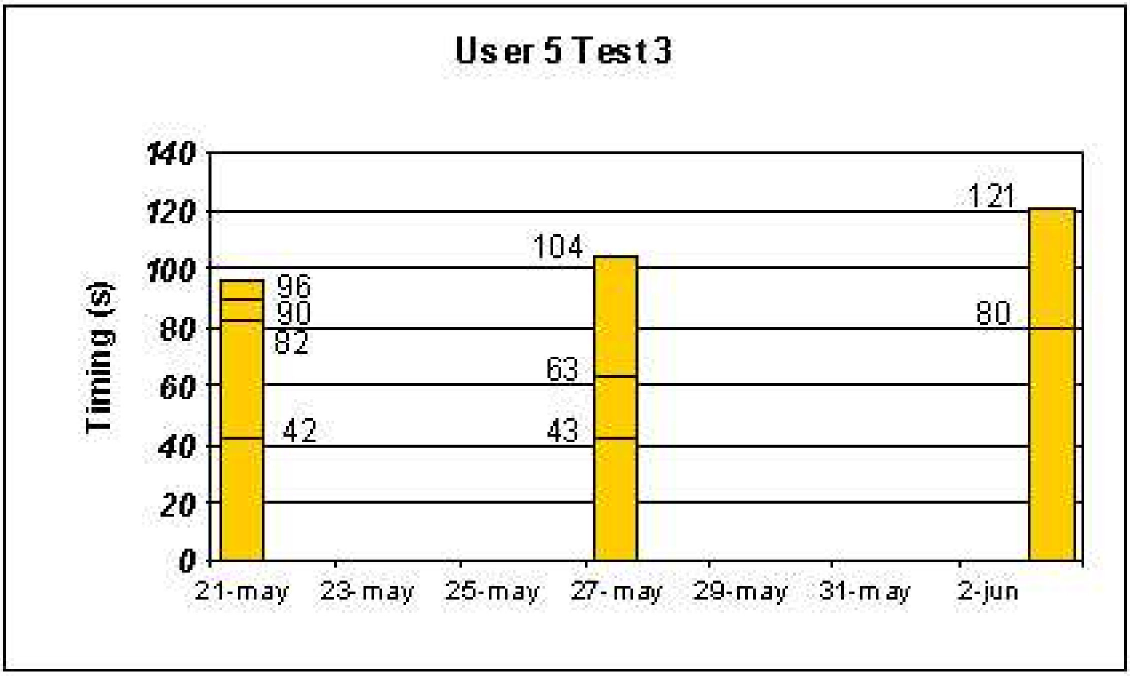


Table A.9: Efficiency tests: Test 1 and 2 for User 5.



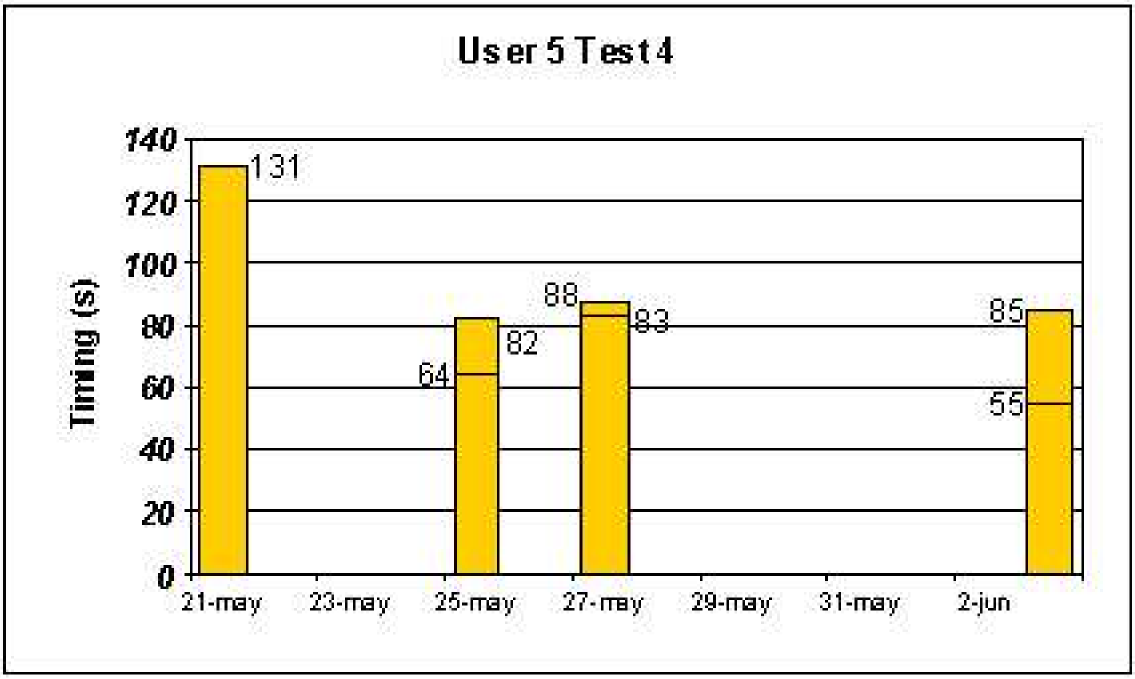
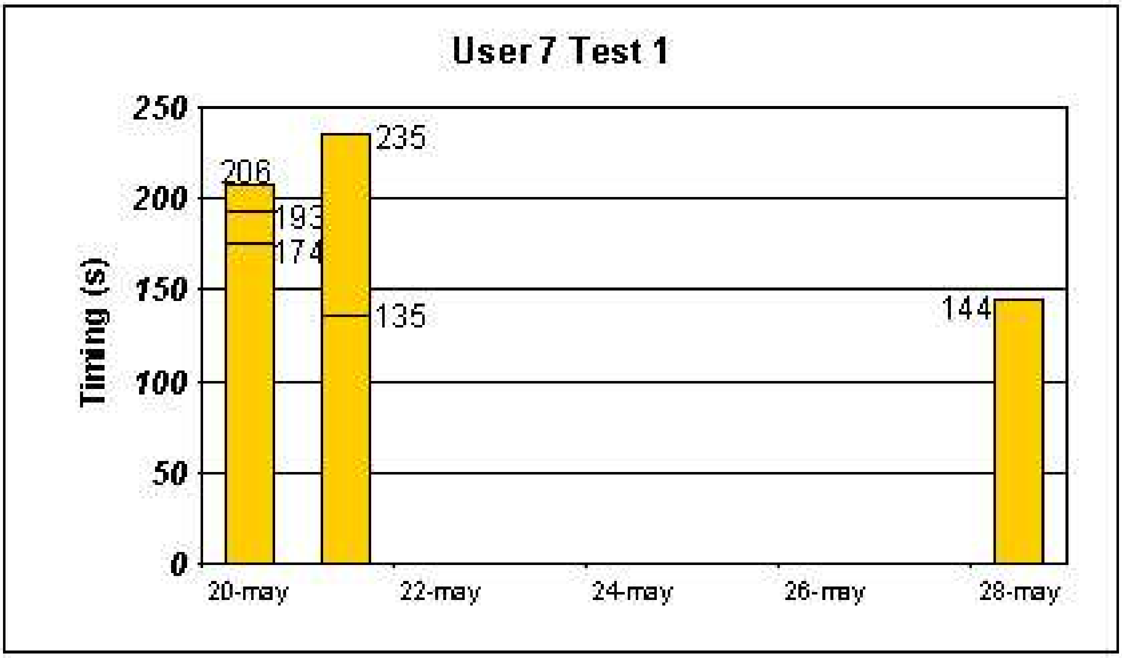


Table A.10: Efficiency tests: Test 3 and 4 for User 5.



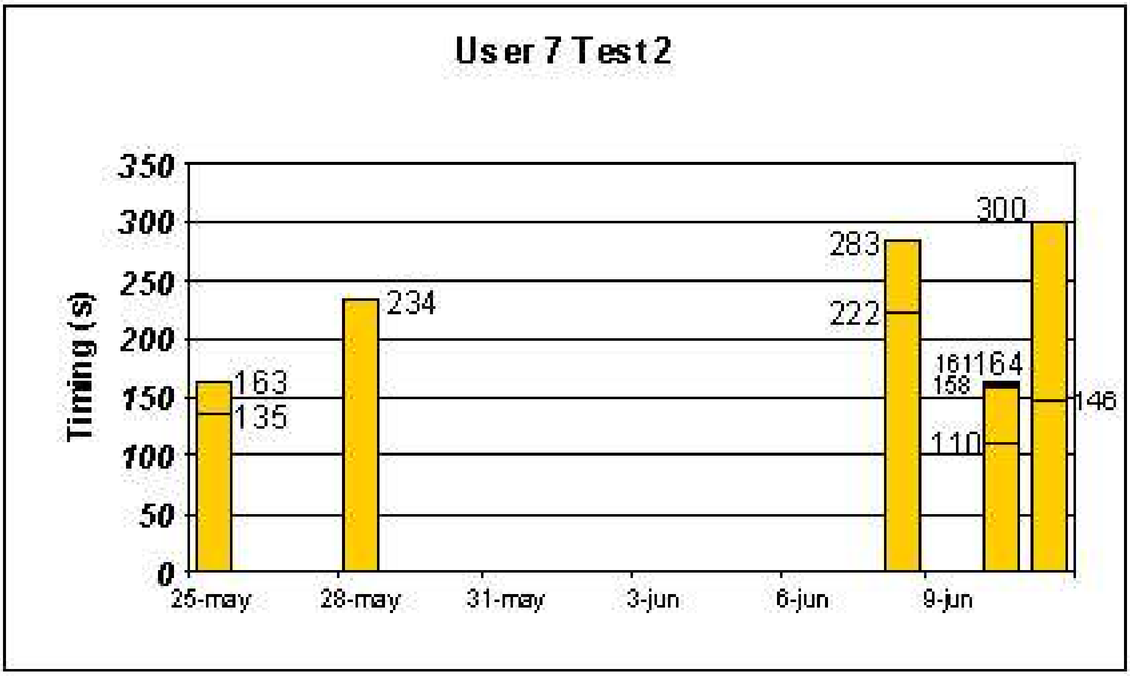
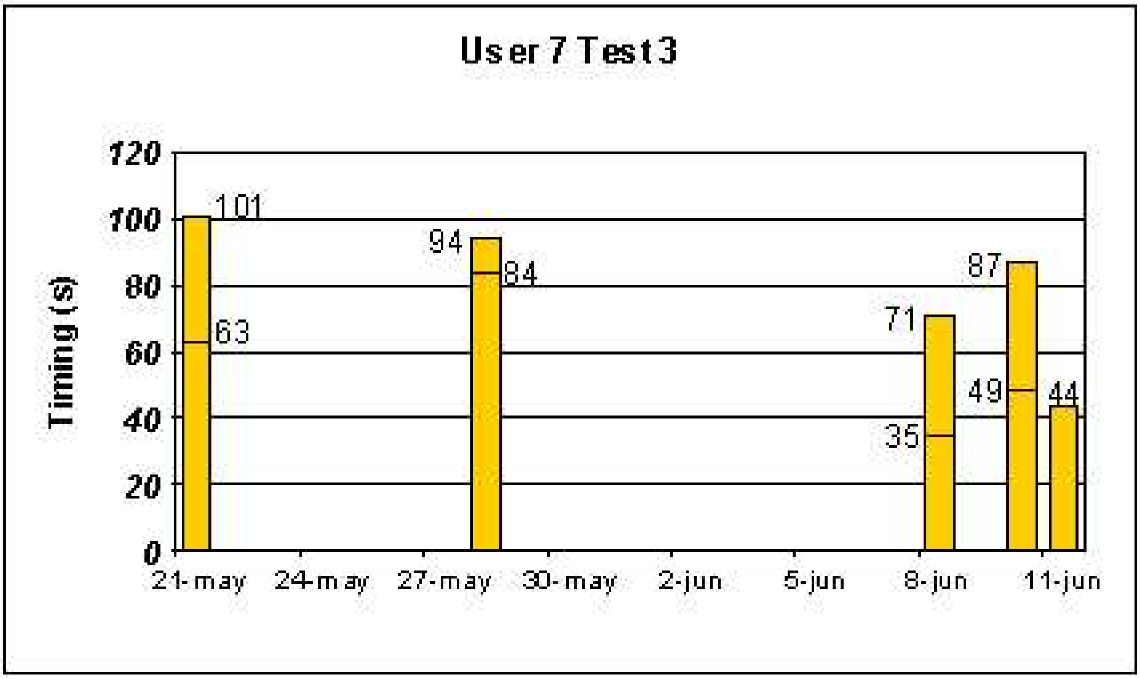


Table A.11: Efficiency tests: Test 1 and 2 for User 7.



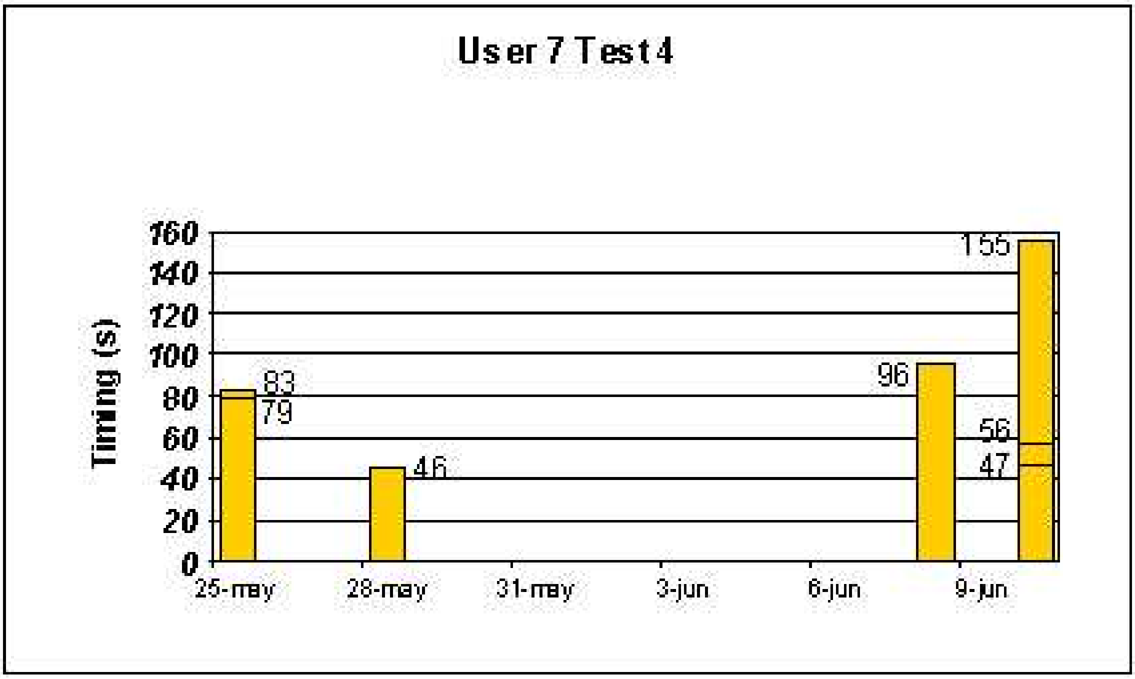


Table A.12: Efficiency tests: Test 3 and 4 for User 7.

A.2.2 Satisfaction

The four questions asked to the users were:

1. Q1: Is it difficult to understand the task?

2. Q2: Is it difficult to use the hands-free interface?

3. Q3: Is the task boring?

4. Q4: Are you tired after using the hands-free interface?

The values of satisfaction are: 1: high, 2:medium, 3: low.

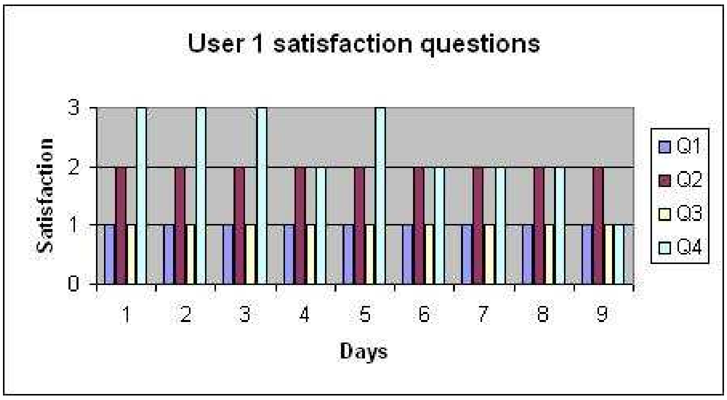


Figure A.1: Satisfaction results for User 1.

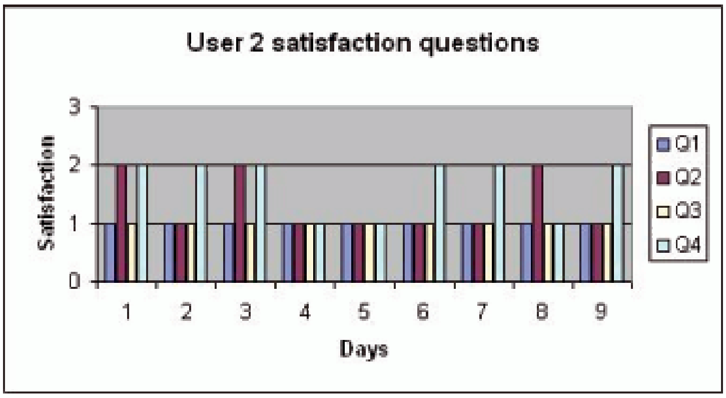


Figure A.2: Satisfaction results for User 2.

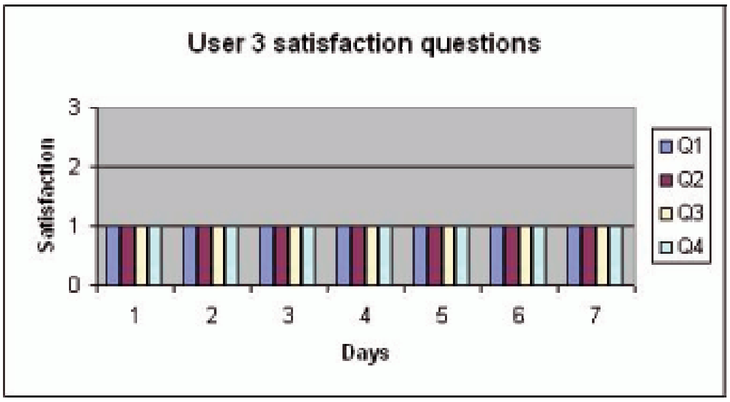


Figure A.3: Satisfaction results for User 3.

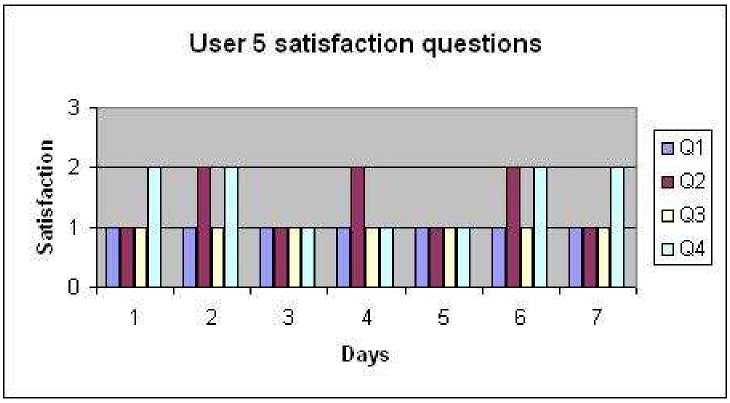


Figure A.4: Satisfaction results for User 5.

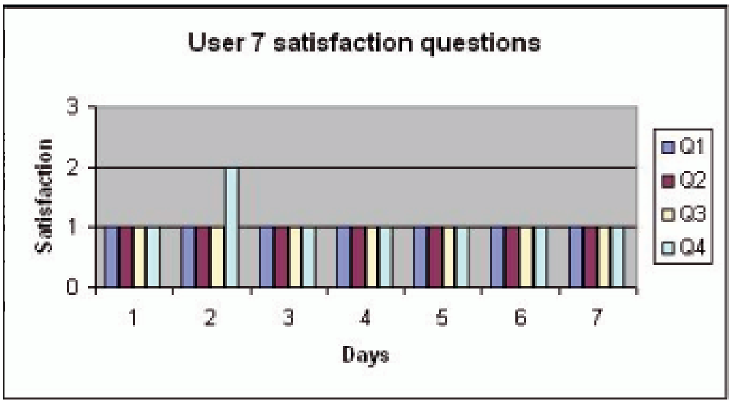


Figure A.5: Satisfaction results for User 7.

Appendix B

User profile

Data	
Evaluator	
User Id	
Day of birth	
Diagnosis	
Medication	

Table B.1: User profile.

MOTOR AREA	
1. SEATED	
Can he sit?	[YES, NO] If No, specify his posture
If Yes	[Standard chair, Own chair] Does he need supports [YES,NO] Which?
Does he have involuntary movements when sitting?	[YES, NO]
Where?	[Hand, Fingers, Face, Feet, Others]
Why?	[Spasticity, Fatigue]
Can he reposition himself?	[YES, NO] If No, with help? [YES, NO]
HEAD POSTURE	
Can he keep his head straight?	[YES, NO] If No, With a support? [YES, NO] Description
If Yes, can he keep his head in the desired position?	[YES, NO]
3. HEAD MOVEMENTS	
Can he control his head?	[YES, NO]
Regarding the movement range	
Flexion	[YES, NO, Obs]
Extension	[YES, NO, Obs]
Right rotation	[YES, NO, Obs]
Left rotation	[YES, NO, Obs]
Rigth tilt	[YES, NO, Obs]
Left tilt	[YES, NO, Obs]
The reaction time when a stymulus is shown is functional?	[YES, NO]
Can the user keep the head position voluntarily enough time to work?	[YES, NO]
The speed movement is	[Too slow, Functional, Too fast]
Does he present involuntary movements (head)?	[YES, NO] Which ones?
Observations	

Table B.2: Motor area.

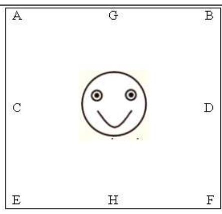
VISUAL-PERCEPTUAL AREA	
Can he fix his sight?	[YES, NO]
Visual tracking:	
	
From A to B: [NO, YES]	If YES: [Continuous, Discontinuous]
From B to A: [NO, YES]	If YES: [Continuous, Discontinuous]
From C to D: [NO, YES]	If YES: [Continuous, Discontinuous]
From D to C: [NO, YES]	If YES: [Continuous, Discontinuous]
From E to F: [NO, YES]	If YES: [Continuous, Discontinuous]
From F to E: [NO, YES]	If YES: [Continuous, Discontinuous]
From G to H: [NO, YES]	If YES: [Continuous, Discontinuous]
From H to G: [NO, YES]	If YES: [Continuous, Discontinuous]
From A to F: [NO, YES]	If YES: [Continuous, Discontinuous]
From F to A: [NO, YES]	If YES: [Continuous, Discontinuous]
From B to E: [NO, YES]	If YES: [Continuous, Discontinuous]
From E to B: [NO, YES]	If YES: [Continuous, Discontinuous]
Does he wear glasses?	[YES, NO]
The visual field is	[Total, Limited]
Does he present visual-perceptive problems?	[NO, YES] What kind?
Can he differenciate colours correctly according to his age?	[YES, NO] If NO, which colours present difficulties?
Can he differenciate figures correctly according to his age?	[YES, NO] If NO, which figures present difficulties?
Is the spatial orientation correct according to his age?	[YES, NO]
If NO, where are the problems?	[Left, Right, Up, Down]
Observations	

Table B.3: Visual-perceptive area.

COMUNICATIVE AREA	
Mother tongue	
Comprenhension	
Does he understand simple orders?	[YES, NO]
Does he understand complex orders?	[YES, NO]
Does he understand when people speak?	[YES, NO]
Expression level	
Has he have a complete vocabulary?	[YES, NO]
Has he have a minimal vocabulary?	[YES, NO]
Can he answer closed questions?	[YES, NO]
How does he express himself	[No expression, Sight, Gestures, Orally (sounds, words), Symbol boards, Voice generator]
Observations	

Table B.4: Comunicative area.

PSYCHOLOGICAL AREA	
Character	
Attitude	
Interested	[YES, NO]
Involved	[YES, NO]
Decisive	[YES, NO]
Creative	[YES, NO]
Others	
Concentration	[Low, High]
Memory	[Short term, Long term, Both]
Reasoning	[Concret, Abstract] Correct for his age? [YES, NO]
Observations	

Table B.5: Psychological area.

PEDAGOGICAL AREA	
Reading	[He cannot read, He reads: [Words, Statements, Texts]]
Writting	[He cannot write, He writes: [He copies: Words, Statements, Texts, He can write without copying]]
His learning capabilities are	[Correct, Medium, Low]
Observations	

Table B.6: Pedagogical area.

ABILITIES WITH THE COMPUTER	
Experience with the computer	[None, Occasional, Regular(Number of hours)]
His knowledge level is	[High, Medium, Low, He does not have]
Can he insert a CD?	[YES, NO]
An a pendrive?	[YES, NO]
Access input device	
Standard keyboard	[YES, NO]
Virtual keyboard	[YES, NO]
Adapted keyboard	[YES, NO] How?
Standard mouse	[YES, NO]
Numerical mouse	[YES, NO]
Adapted mouse	[YES, NO] How?
Observations	

Table B.7: Abilities with the computer.

Appendix C

Sessions spreadsheet

Evaluator information	
Name	
Category	
User information	
Id	
Session information	
Session n^{o}	
Data	
Place	
Start time	
End time	
Computer	
Id	
Screen configuration	
Accessibility options	
Other comments	

Table C.1: User profile.

Environment	
Is the user motivated?	[YES, NO] If No, Reasons
His physical state is	[NORMAL, DEFFICIENT] If it is DEFFICIENT, comment his physical state
Description of the user's initial posture	
Position of devices	
Screen	
Webcam	
Evaluator position	[LEFT, RIGHT, OTHER]
Lighting type	[NATURAL, ARTIFICIAL]
Description of the position of the user considering the light	
Observation and description of interferences	

Table C.2: Environtment conditions.

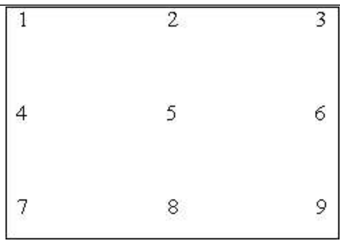
Hands-free interface	
Configuration	
X jump:	Y jump:
Click time:	Click range distance:
Features lost?	[NO, YES] If YES, number of times
Nose point displaced	[0 times, 1-3, 4-6, MORE]
If there was displacement, did it affect the operation of SINA?	[YES, NO]
Displacement direction? Reasons	
Screen coverage	
Mark the accessible zones	
Cursor's motion	[TOO SLOW, CORRECT, TOO FAST]
Task	
Technical errors	

Table C.3: Hands-free interface.

Usuari	
Head motion control	[TREMBLING, FIRM, UNCONTROLLED, CONTROLLED, SLOW, FAST, RELAXED, DISASSOCIATED, CONTINUOUS, DISCONTINUOS]
The user presents posture disorders	[NO, YES] If YES, which ones?
Does he present fatigue?	[NO, LITTLE, A LOT]
Does he need help?	[NO, YES]; If YES, what kind of help? [PHYSICAL, VERBAL, OTHER]
Does he understand and follow the instructions given?	[YES, NO]

Table C.4: User.

User/Program interaction	
Does the user present visual problems for interacting	[YES, NO] If YES, what kind of problems?
His coordination "gaze-head motion" is	[NULL, LOW, GOOD, IMPROVES WITH PRACTICE];
He presents problems of	[ATTENTION, INTEREST, COMPRENHENSION, SPATIAL ORIENTATION]
Considering the spatial orientation:	
He follows the correct direction?	[YES,NO]. If NO, can he reach the target? [YES, NO]);
Describe the problems he presents	
Does he present other kind of problems?	[YES, NO]. What kind?
Satisfaction level is	[HIGH, MEDIUM, LOW]
Other remarks	

Table C.5: User/Interface interaction.

Appendix D

Satisfaction questionnaire

D.1 Action Protocol

The therapist should agree with this questionnaire.
Intructions for the therapist:

Next, I will ask you some questions that may be a problem for some children. I would like to know how much of a problem are these issues.

We have to show the pattern to the children and they have to point the correct answer. The therapist will mark the appropriate answer on the satisfaction questionnaire.

- If the answer is *No, not at all*, the user will point the happy face.
- If the answer is *Sometime*, the user will point the face in the middle position.
- If the answer is *A lot*, the user will point the face in the frowning face.

We will ask a question as an example:

Is is difficult for you to move one or both arms?		
No, at all	Sometimes	A lot
		

Table D.1: Example of question. Faces' images [6, 19].

We have to verify that the user understands the question and knows how to answer. We should repeat the question if the answer is not clear.

Now, the user is prepared to answer the satisfaction questionnaire.

User :	Therapist:	Evaluation date:
Activity:	Interface:	
We ask for your cooperation in order to mark the answer depending on the user's answer. These questions are related to the task and his comfort.		
Questions for the user:		
1. Is it difficult to understand the task?		
1	2	3
No	Sometimes	A lot
2. Is it difficult to use the interface?		
1	2	3
No	Sometimes	A lot
3. Is the task boring?		
1	2	3
No	Sometimes	A lot
4. Are you tired after working with the interface?		
1	2	3
No	Sometimes	A lot

Table D.2: User's questionnaire.

Therapist observation:			
We ask for your cooperation for adding comments and recommendations to improve the task, the interface and the assessment in the user's monitoring.			
Task:	Interface:		
5. Does the user understand how to move the cursor with the interface?			
1	2	3	4
Perfectly	It seems he understand it	It seems he does not understand it	No
6. Does the user understand how to execute an event with the interface?			
1	2	3	4
Perfectly	It seems he understand it	It seems he does not understand it	No
User:			
7. Does the interface improve the user's posture?.			
1	2	3	4
A lot	A little bit	No	His posture is worse
8. Can he keep his head straight when he works with the system?			
1	2	3	4
During the whole session	During a part of the session	Only in the initialization	No
9. Does the user get tired when working with the system?			
1	2	3	4
No	A little	Quite	A lot
10. Does the user's neck get tired?			
1	2	3	4
No	A little	Quite	A lot
11. Does the user present involuntary movements when using the system?			
1	2	3	4
No	They decrease	The usual ones	More than usual

Table D.3: Observations of the therapist.

Satisfaction questionnaire for the therapist			
We ask for your cooperation to answer your perception over issues related with the interface.			
12. The cursor's movement has been:			
1	2	3	4
Very smooth	Smooth	Abrupt	Very abrupt
13. The user's body movement when using the interface has been:			
1	2	3	4
Very smooth	Smooth	Abrupt	Very abrupt
14. The effort for using the interface has been:			
1	2	3	4
Null	Little	Quite	A lot
15. Once configured the system for the user, the accuracy has been:			
1	2	3	4
Very correct	Correct	Not too correct	Very incorrect
16. Once configured the system for the user, the speed has been:			
1	2	3	4
Very correct	Correct	Not too correct	Totally incorrect
17. The general comfort has been:			
1	2	3	4
Very comfortable	Comfortable	Not too comfortable	Very uncomfortable
18.The general operation with the interface has been:			
1	2	3	4
Very easy	Easy	Quite difficult	Very difficult
19. The facial detection has been:			
1	2	3	4
Very fast	Fast	Slow	Very slow
20. The loss of the nose feature with no reason has occured:			
1	2	3	4
Never	Few times	Many times	Too many times
21. The displacement of the nose feature has occured:			
1	2	3	4
Never	Few times	Many times	Too many times

Table D.4: Questionnaire for the therapist.